PAPERS OF THE
ROBERT S. PEABODY FOUNDATION
FOR ARCHAEOLOGY

VOLUME TWO

THE BOYLSTON STREET FISHWEIR

A STUDY OF THE ARCHAEOLOGY, BIOLOGY, AND GEOLOGY OF A SITE ON BOYLSTON STREET IN THE BACK BAY DISTRICT OF BOSTON, MASSACHUSETTS

BY

FREDERICK JOHNSON

IN COLLABORATION WITH

Henry C. Stetson, Frances L. Parker, William J. Clench, Thurlow C. Nelson, David H. Linder, Irving W. Bailey, Elso S. Barghoorn, Edwin C. Jahn, William M. Harlow, William S. Benninghoff, Arthur S. Knox

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Fig. 1. Map of the Boston Peninsula and surrounding regions about 1700. Index Map after LaForge showing geomorphic subdivisions of the Boston area.

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PREFACE

THIS study describes a Fishweir which formerly occupied more than two acres of the Back Bay district in Boston, Massachusetts. This Fishweir is evidence of the most ancient existence of man which has yet appeared in eastern North America. If this study must be classified, it belongs within that section of archaeological research which is concerned with the first arrival of the aborigines, that is, the study of ancient man. Such a classification may seem presumptive because the hypothetical date suggests an antiquity of but a few thousand years. However, the method by which this date was ascertained involved techniques, basic theories and assumptions which are applicable to any study of ancient man.

Archaeologists are slowly recognizing that their field is no longer susceptible to strict definition. The problems which are being attacked, especially that of ancient man, have many important ramifications. The fact of the interdependence of archaeology and geology has been firmly established, especially in the approach to the later phases of the geology of North America which include the remains of ancient man. However, before the significance of these phases can be estimated, contributions from palaeobotany, and studies of all the organisms from specific deposits must be interpreted. It is obvious that archaeologists must not only produce evidence of the occupation of a region and of specific strata within a region but they must also be in a position to assimilate data regarding the provenience of their evidence, this data being supplied by a host of interlocking investigations.

Concerning the problem of the antiquity of man in North America, Bryan and Ray have aptly said, "The geologic approach is attended with difficulties which arise from the lack of immediate precedent as to method and from the lack of a well-established geologic chronology applicable to the whole world." The present study utilizes the geologic approach to the problem of the antiquity of the Fishweir. As such, it supports the statement quoted above. In addition, equally important analyses have been contributed by other fields. The resulting extensive collaboration, when combined with previous studies of the same situation, is the first effort to apply modern concepts of the interrelationship of scientific fields to the problem of the antiquity of man east of the Mississippi River.

Lacking a precedent, it has been necessary to obtain and organize the data on the basis of their own merits as they are shown against the background of similar researches in vogue in Europe. Not without some influence on the

present procedure were the relatively few attempts to solve the problem of the antiquity of man in western North America. The present study differs from other American studies in that it deals with the complications of a coastal environment. Then too, progress has been hampered by the lack of contributing data. Lack of time and resources has prevented a new study of the geology of the site and thus it has been necessary to search for such data in independent studies which were made for wholly different purposes.

During the first days of the present study the interrelationship of various fields of research was recognized. Preliminary attempts to state the problem only served to outline further problems and to point out various phases which required, for their explanation, expert techniques, knowledge, and interpretation. With some trepidation at first, and later with some confidence, appeals for enlightenment were made to a number of men in as many fields. The response was most magnanimous, for, without exception, these men recognized the value and necessity of collaboration and immediately set to work on the various phases of the investigation. The results of these researches are embodied in this volume. They speak for themselves.

Though it is a great pleasure, it is something of an anti-climax, to attempt to express adequately the appreciation of the Foundation and me for what has been done by these men. During the process of assembling this report I have attempted to enlarge my perspective and this has been done at the expense of the collaborators. I have had the audacity to push my way, frequently and unannounced, into the laboratories of these men, to take up their time with questions and discussions which at times were most elementary. To say that I have profited greatly from their patient explanations is indeed putting it mildly.

An acknowledgement of the obligation by the Foundation and by me is incomplete until numerous friends have been included. For the past two years I have talked nothing but "Fishweir" to a large group of people. They have responded with enthusiastic and cogent discussions of all aspects of the problem. This report would indeed be incomplete were it not for their contributions. Unfortunately, it has not been possible to recognize properly the ideas which have come from these conversations, but it is certain that that they form the backbone of the whole argument. I mention only my wife whose tolerance and criticism have been of inestimable value.

One man is, in truth, a major contributor even though his name appears only as an author of quoted reports. Dr. Kirk Bryan has been, from the very beginning, an enthusiastic and friendly counselor. He has read the manuscript and I have tried to profit by his searching, objective criticism. I am also eternally obliged to him for his patient forbearance of my igno-

rance of geology even after I had disregarded his previous advice, warnings and even threats. For ten years or more I had put off the day when I should delve into the intricacies of fact and expression so characteristic of the geological world.

One of the most remarkable things about this study is the relation between it and the New England Mutual Life Insurance Company, the owners of the site on which the Fishweir was found. Through the President of the Company, Mr. George Willard Smith, every conceivable bit of aid and encouragement has been extended. The impossibility of expressing one's gratitude to a huge organization is somewhat ameliorated by contact with its personnel. I hope that each and every one of the men in the Insurance Company has realized long before now how much his friendship and support have aided the work.

The relation of the Insurance Company to the study goes beyond the confines of its own walls. The Turner Construction Company, which was making the excavation for the foundation of a new building for the Insurance Company, was asked to cooperate. Would that everyone define cooperation as does the Turner Construction Company! Through the friendly offices of Mr. L. S. Homer, Field Superintendent, I was given an unprecedented amount of liberty and an unusual amount of material aid. Engineers were instructed to do my bidding and laborers were assigned to help. To say that the progress of my work in the excavation was not impeded or interrupted by power shovels, trucks or other of the impedimenta of a large construction job serves only to indicate what was done for me.

In a preface of this sort the words of appreciation not only recognize those who have aided, but they constitute a description of the background for the study. Such is incomplete without mention of the Trustees of Phillips Academy, who, through their representatives, Dr. Claude M. Fuess, Headmaster and Mr. Douglas S. Byers, Director of the Foundation, have given me time to complete this work.

To the American Academy of Arts and Sciences I am deeply indebted for a Grant in Aid which, when added to funds supplied by the Foundation and other sources, made the actual publication possible.

A final word may be said concerning the origin of the present publication. Dr. Henry Howe, of Cohasset, heard that the foundations for the Insurance Company's Building were to be laid unusually deep. He immediately wrote the Foundation asking if perhaps the original situation reported in 1913 might not be rediscovered. Mr. Byers passed the information on to the Insurance Company and they, in turn, provided the engineers and workmen of the Turner Construction Company with photostat copies of

Mr. Willoughby's description published in 1927. All who are interested in the problem owe a debt of gratitude to the foresight of Dr. Howe and to the eagle eyes of the engineers and the power shovel operator who first spotted the stakes in the mud.

A note should be made concerning the organization of this report. It is divided into three parts. Part I is a single unit consisting of a detailed description of the deposits and the remains of the Fishweir. Part II is divided into ten chapters each of which deals with different phases of the investigation. Each of these chapters is under separate authorship and is treated as a unit. Part III is a discussion of all the data presented in Parts I and II together with information obtained from other sources. This part is organized as a separate unit. With such an arrangement it should be possible to find, without great difficulty, detailed accounts of specific facts. These will appear in Parts I and II. Discussion of the significance of these facts, in respect to the site itself, may be found under appropriate headings in Part III.

FREDERICK JOHNSON

INTRODUCTION

IN 1913, during the construction of the Boylston Street Subway through the Back Bay district in Boston, the workmen discovered a number of decayed, upright stakes, interlaced with horizontal "wattling" buried deep in the silt beneath Boylston Street. These were believed to be the remains of an ancient fishweir which was formerly located under Boylston Street between Berkeley and Clarendon Streets. The implications of this discovery have been briefly suggested in the descriptions of the stakes and the surrounding deposits.[1] The results of the present study illuminate these implications to a degree which permits us to see further into the problems surrounding the determination of the antiquity of man in eastern Massachusetts if not the whole of eastern New England.

There is described a structure, certainly made by man, which is tentatively called a Fishweir. This Fishweir was composed of about 65,000 stakes which were distributed over more than two acres of the former mud flat and marsh land which was the forerunner of the Back Bay region (Fig. 1). The very size of this structure implies, if it does not constitute proof, that at some time the region supported a community of appreciable size. It is impossible to conceive of such a structure being built and maintained by a few people, especially when one realizes that all these stakes had to be laboriously cut, sharpened, and driven with handmade, stone and wooden tools.

Again, the structure implies a certain amount of communal organization for there must have been some one person or group which was responsible for the execution of the plan. This implies a division of labor and a division of the spoils. Such implication might even be carried further, with a number of conjectures regarding the economic and social life of these early residents of the Back Bay section. In other words, it is probable that there existed a thriving community which maintained a fishweir in addition to possessing all the characteristics of human existence which may be included in the broadest definition of the term culture.

Another intriguing fact about the Fishweir is its antiquity. Even lacking the details presented here, such a rather obvious fact as the significant rise

[1] The discovery was first reported by the Boston Transit Commission (Davis, E., 1913). Dr. Hervey W. Shimer discussed the significance of the location (Shimer, 1918) and Mr. Charles C. Willoughby described the stakes and attempted an interpretation of the site (Willoughby, 1927). These reports have been the basis for a number of discussions (for example: Antevs, 1928a, p. 93; Hörner, 1929, p. 140; Willoughby, 1935; Davis, W., 1938; Morris, Albert, 1941).

in sea level, occurring after the abandonment of the weir, is sufficient ground for a belief in an antiquity which may be measured in a few thousands of years. The fact of antiquity has a number of implications. Recent discoveries of ancient man in western North America have associated Folsom man with phenomena closely connected with the last phases of the glaciation of the continent. The Folsom occupation, which is not evidence of the first man in North America, has been tentatively dated as occurring about 25,000 years ago.[2] Whether this date will stand or not is immaterial. What is important is that North America has been populated for a lengthy period.

The realization of the antiquity of the Fishweir has, from the point of view of North American Archaeology, a number of engaging, if not important, implications. It may well be asked, is the Fishweir evidence of the first occupation of the region? If this is so, is it not possible to stimulate one's curiosity with the questions: was the Fishweir made by immigrants who were related to those who succeeded Folsom man; were these successors descended in a direct line? Or, are we dealing with a completely different group of immigrants who arrived in New England without previous contact with Folsom?

If we may assume, for the moment, that the social and economic organization of the people which is implied by the very presence of the Fishweir indicates the presence of a large and thriving community, it is not easy to assume, in addition, that the builders of the structure were the first people to arrive in the region. We can thus pose a question: how long was it between the first occupation of the region and the time when the Fishweir was built?

Having proposed these questions, it remains to discuss what may be done. Our knowledge of this part of the continent does not permit a proper evaluation of the facts which have been brought to light in the present study. Except for certain details, there is nothing with which to correlate the facts which have been amassed. Consequently, the study of the Fishweir stands alone as a unique one awaiting future explanation of its many complications. The primary questions cannot yet be answered.

If we may ignore categorical and unfounded statements of a sentimental nature, it may be said that aside from this Fishweir there is no existing evidence of the domestic life of the aborigines of New England from which even an acceptable hypothesis of an antiquity of more than a few hundred years may be drawn. The exception to this statement is the Indian camp site at

[2] Bryan and Ray, 1940; Bryan, 1941.

Grassy Island in the Taunton River.[3] Unfortunately, however, present evidence regarding this site is incomplete, so that several important steps in the argument for antiquity are controversial. Since we do not know of any ancient sites, we cannot assign any type of culture to the community which built the Fishweir, we have no way of identifying these people, and we have nothing with which to compare them. Consequently the answers to questions concerning the people themselves will have to await the results of future investigations.

The problem of the antiquity of man, excepting the evaluation of his physical and cultural characteristics, is not purely an archaeological problem, if that field is to be kept within the absurdly narrow limits of strict definition. One of the most important factors in the identification of ancient man is the location in which his remains are found. The interpretation of these locations falls upon the shoulders of the geologist. This is particularly true of the Fishweir site, where one of the most prominent and definite of the proved facts is the rise in sea level. However, a strict geological study of such a situation is of little value until it can be included in the complete story of the evolution of the region.

The rise and fall of sea level, which can also be expressed in terms of the submergence and emergence of the land, is only one of the many different characteristics of the region. The effects of glaciation, particularly the fluctuations of level subsequent to the recession of the ice, can only be determined through a careful study of many deposits and of other geologic features distributed over a wide area. Once this has been done, the fluctuations may be correlated, in a very general sense, with changes in climate which have been discovered by other studies. The changes which appear in a climatic sequence can, in some measure, be used as landmarks. These landmarks may be dated after they are properly evaluated and compared with other data originating in various independent studies. Because of these complications, the geologist or archaeologist can proceed but a short distance without aid from the many fields which provide him with information regarding the ecology of the deposits in which he is interested.

These remarks help to point out that before the final evidence can be assembled in the form of answers to the primary questions, a number of fundamental problems have to be solved. Characteristics of human existence have to be determined and these have to be arranged in appropriate geographical and chronological relationship. Further, data from many other fields of scientific research have to be appraised. Limiting details regarding

[3] Delabarre, 1925, 1928; Goldthwait, 1940.

the rise in sea level have to be determined. The evolution of climate has to be proved and described in detail. This latter includes a study of the fauna and flora of the site. Even this does not answer the primary questions, for it is necessary to go through a similar procedure for the whole region. Every contributing study deals with phenomena which have a very significant horizontal or geographical distribution in addition to the vertical one. In this study we are forced to be content with the vertical section. The amount of data which supplies any knowledge of the horizontal distribution of the materials is indeed meagre, not to say controversial. We are therefore submitting a study which is unique with the hope that its possibilities will be recognized and that future research will not permit it to stand long alone.

It is well to review what was known of the Fishweir before the present study was begun. The various measurements given in investigations[1] of the stakes discovered in 1913 vary slightly. One gathers that separate measurements were taken on at least three stakes and published in as many places. These differences are, however, of no great importance, for it is obvious that the reports are describing practically the same situation. The investigations show that beneath Boylston Street about eighteen feet of fill had been dumped, after 1856, upon a stratum of silt, which was fourteen feet or more deep. The silt rested upon a stratum of blue clay, which was about one hundred feet thick.

It is impossible to determine how many stakes were uncovered in 1913, but there is a general opinion that many were destroyed by the workmen. These stakes varied in length from four to seven feet. The one described by Willoughby was forty-six inches long and, "Originally the upper portion was probably longer, for the top seems to have been broken off during the removal of the earth above."[4] These stakes had been driven into the blue clay a distance of eighteen inches and the upper portions were included in the overlying silt. The lowest wattles preserved lay in the silt about eighteen inches above the blue clay. Dr. Shimer, in an interpretation of the significance of this location, says, "If we consider the lowest preserved horizontal sticks as originally the lowest and as resting upon the surface of the mud when erected, then about thirteen feet of shells and mud had been deposited between the time when man planted the fishweir and when he blotted out the Bay. If we consider the possibility that there was practically no silt when the weir was erected, it would mean the deposition of fourteen feet eight inches of sediment between that time and the artificial filling of the Bay."[5]

[4] Willoughby, 1927, p. 105.
[5] Shimer, 1918, p. 460.

In discussing the deposits surrounding the Fishweir, Dr. Shimer says that theoretically they have passed through five general stages of development.[6] These may be summarized as follows:

1. The underlying blue clay, the so-called glacial flour, was derived from a nearby melting glacier and was probably deposited in bodies of fresh water.

2. Following the disappearance of the glacier, the clay was exposed to the air so that the upper layers were hardened through oxidation. In addition, sections of the surface were eroded by running water.

3. During this erosive period (2. above) or, at least, during the latter part of it, fresh-water peat was broadly developed.

4. Following the deposition of the peat, a large portion of the region sank, with reference to sea level, and was covered by the sea. This period of submergence has extended to the present. During this time occurred the deposition of the black mud (silt), in which were enclosed the shells and other records of life then living in these waters. The evidence furnished by the peat, if it was formed at sea level, indicates that there was a submergence of at least forty-three feet. If the peat was formed far above sea level, it would mean that the amount of submergence would be increased by an amount equal to the original elevation of the peat. This record of submergence contains two distinct elements. (*a*) In the earlier of the lower beds, which are about four feet thick, the marine shells indicate a warm climate, or at least, warmer water, similar to that between Cape Cod and Cape Hatteras at present. (*b*) The upper beds, some nine feet thick, and where still beneath the sea, continuing to the present, contain a marine fauna indicative of a colder climate similar to that of today.

If it is possible to judge from the Back Bay sections, this change from a warm water fauna to one characteristic of colder waters, was abrupt and was due to a corresponding alteration in climate. It is not probable that a refrigeration of the ocean waters alone could have made its influences felt so very decidedly as far inland as Back Bay (see Index Map. Fig. 1). It is not likely, either, that all the differences between the more fossiliferous lower portion (4a), with its warm water fauna, and the upper portion (4b), with its few fossils, indicative of colder water, are due to the partial closure of Back Bay by the tidal building of Boston Neck. This partial closure, bringing about a reduction in tidal scour, would, of course, cause a more rapid accumulation of sediment within the Bay and hence relatively fewer fossils. The very great change, however, in the species represented, especially in

[6] Shimer, 1918, pp. 456–459.

the reduction both in number of individuals and species, would seem to imply an accompanying climatic change. That this refrigeration continued during colonial days to the present is indicated by the disappearance of oyster banks from the vicinity of Boston (Charles River, Mystic River, and East Boston flats) and by the inability of planted oysters to grow here now.

5. In certain areas, as Back Bay, the land was raised again from its ocean bed by artificial damming and filling of the area.

In contemplating the depth of the weir, Shimer pointed out that at the present relation of land to sea, the weir would have been driven into water sixteen feet deep at low tide, or twenty-six feet deep at high tide. To accomplish this, the sticks would have had to be twenty-nine feet long to reach from the high tide level to a point eighteen inches below the surface of the blue clay—and these sticks had a diameter of only two inches at the base. "Since the construction of a fishweir under such conditions is practically impossible, it must be assumed that erection took place before the land had become submerged to its present depth. If we may judge from the practice of today, the weir was erected when the region was exposed at low tide, or almost so, and covered at high tide. If so, the land has sunk sixteen to eighteen feet since man placed here his fishweir."[7]

In the previous accounts, the discussion of the time required for this submergence to take place was embodied in the discussion of the age of the Fishweir. There were, however, other factors which were taken into consideration. The presence of fossil shells was believed to indicate that parts of the weir extended above the encroaching sediment during the time necessary to deposit three or four feet of shells and mud, next to suffer a striking climatic change and finally to deposit another foot or two of sediment. These changes could not have taken place in a few years. The determination of the time required to deposit the silt which covered the weir, some thirteen to fifteen feet, according to Shimer, was largely a matter of conjecture. He suggested, with qualifications, that, if the Charles River deposited silt at the rate similar to that estimated for the Mississippi River, i.e. one foot in two hundred years, it would have required 2500 to 3000 years for the accumulation of this thickness. He also suggested that the presence of the oyster beds were evidence that the tidal scour was stronger during the existence of the warmer climatic fauna and weaker during the formation of the upper, colder beds. Shimer concluded that "On the whole it may be considered as probable that the accumulation of silt here had been at least no faster than that by the Mississippi at present."[8]

[7] Shimer, 1918, p. 462.
[8] Shimer, 1918, p. 461.

Dr. Shimer's estimate that the Fishweir is between 2500 and 3000 years old is interesting in view of Willoughby's calculation. The settling of a bronze plate on the dry dock in Charlestown was the basis for an estimate that the land about Boston was settling at the approximate rate of one foot per century. Assuming the subsidence of the land was uniform, he concludes that the weir must have been built about 1400 years ago. Willoughby found that this date corresponded rather closely with 1200 B.C., a date at which, according to Dr. Paul B. Sears, a warm dry period reached its climax.[9]

At the time this information was gathered, it was as complete as the circumstances permitted. It is true, however, that many questions have needed elucidation. Because of the situation of the discovery in a tunnel excavation, it was impossible, in 1913, to carry on extensive investigations which would supply necessary important details. The identification of the mollusks from the different levels in the silt was done with some care, but finer details of their provenience could not, under the circumstances, be determined. For many reasons, other organisms in the silt and other strata were not identified. Problems suggested by the presence of a peat layer in surrounding areas could be discussed only in general terms, for unfortunately, peat was not found in association with the stakes. Regarding the stakes themselves, but little, aside from a partial determination of their location, could be said. The horizontal sticks were identified as wattles woven among and tied to the vertical stakes on the basis of a really slight amount of observation. In addition, it was impossible to do more than guess at the identification of the wood. The analysis of the facts obtained, though of great value, left much to be desired, because the lack of data made it necessary to base final interpretation upon a series of assumptions. The basis for determining the amount of submergence of the Back Bay since the stakes were driven was purely an assumption that the stakes were part of the Fishweir. Furthermore, it was assumed that the weir was used when the level of Mean Low Water bore a certain definite relationship to the level of the bottom of the Bay. While such an assumption may be justifiable, it is, in the final analysis, only slightly better than a guess and is thus not too sound a foundation. The recent analysis, made under more favorable circumstances, will show (*a*) that there is only circumstantial evidence to prove that the stakes were part of a fishweir, and (*b*) that even if the stakes were the remains of a weir, there is no basis for the postulation of a particular association between it and certain tide and mud flat levels. The location and relationship of tide and mud flat levels can be discussed in the light of additional and more recent evidence.

[9] Willoughby, 1927, 1935.

The question of the length of time which has elapsed since the stakes were driven may never be settled. It is hoped, however, that the data presented will add to that in existence, so that the knowledge of some of the characteristics of the sedimentation of the Back Bay will be more complete. However, such addition of fact will not make possible an accurate determination of the age of the deposits in terms of a definite number of years, for as yet the geochronological time scale developed for New England is extremely hypothetical. It may be added that the former use of such criteria as the supposed settling of the Bench Mark on the Charlestown Dry Dock was hardly justifiable. The changes of position of the plate were first investigated and discussed in 1903,[10] and the resulting vitriolic discussions threw sufficient doubt upon the possibility of its being an indication of the subsidence of the shore line to vitiate the argument.

Changes in climate during the history of the deposit were based primarily upon the evidence of the mollusks. The evidence obtained by Dr. Shimer was and is conclusive as far as it goes. However, in view of the ability of mollusks to live outside their theoretical range, and to exist under many exceptional conditions, the evidence was not over-satisfactory. The recent investigations have added various other types of life to the list of fauna and flora so that the levels exhibiting different types of climate may be described in more detail. In addition, the character of the change is described more precisely.

The preceding attempt to indicate generally the problems connected with this discovery may appear as severe criticisms of previous work. Such is most certainly not the case, for the work has been of utmost value and still remains so. The appearance of criticism comes, as it does in most scientific endeavor, when new developments and additional facts are added to those which have already come to light. It is obvious that the addition of new details will necessitate the revision of previous opinions.

The principal significance of this rediscovery lies in the opportunity for meticulous study which was provided. The recent finds were made during the excavation for the foundation of the New England Mutual Life Insurance Company's building located in the block bounded by Boylston, Clarendon, Newbury, and Berkeley Streets (Fig. 1). This block also includes the property of the Boston Society of Natural History. At the bottom, this excavation was approximately 337 feet long, parallel to Boylston Street, and 194 feet wide, parallel to Clarendon Street. There was some variation in the depth of the excavation, but throughout its extent it reached the level

[10] Freeman, 1903, pp. 529–531.

where the weir was to be found. Evidences of the weir were distributed over nearly sixty-five thousand square feet, approximately the area uncovered by the construction company. This extensive open hole provided continuous and large scale observation of the stakes and their relationship to the surrounding deposits. It was possible to work out the finest observable details of the cross section along the banks surrounding the excavation and on the sides of the many "cuts" made inside the periphery by the power shovels. This section extended downward from the street level to points below the surface of the underlying blue clay. Additional information was obtained from the records of borings. The opportunity to study the complete cross section of the excavation exposed from top to bottom was enlightening in that it produced numerous impressions in addition to recorded detail. Of added importance was the opportunity to check all details of this cross section accurately and frequently, at any place over the whole area of the excavation.

Details concerning the construction and actual location of the remains of the Fishweir were obtained by careful, controlled excavation, during the course of which all appropriate methods of archaeological excavation and recording were applied. Because of its extent, and because of necessary building operations, it was not practical to attempt a complete excavation of the weir. Furthermore, even at the very beginning of the work, it was apparent that the conditions over the whole of the excavation were analogous, and such extensive work was not warranted. The procedure followed involved the collection of detailed data from a trench and the checking of this data in all sections of the area by following closely the progress of the power shovels. The observation of the phenomena exposed by the power shovels produced very little data which were not plainly visible in the trench, and it is believed reasonable to assume that the data, perhaps excepting the horizontal plan, is sufficiently complete.

The remarkable conditions provided by this huge excavation made it possible to obtain carefully located specimens and samples for analysis. All samples were numbered and a record of their provenience was made.[11] Thanks to the interest of the Turner Construction Company, the trench was left open until nearly all observations had been made. This made it possible to locate all observations or collected samples directly on one cross section—that from the trench. The value of this was not apparent until it was found that preliminary analyses of collected material proposed new problems

[11] Only the vertical measurement, including a note of the stratum from which the samples came, was made. There seemed to be little or no significance in the horizontal location of these samples.

which required, for their solution, additional samples of known provenience. It was possible to return repeatedly for new materials. After an appraisal of all the data, it seems reasonable to assume that, with the exception of some details, the information which we now have represents a unit which describes within reasonable limits of accuracy and completeness the stakes as they appeared over an area of some sixty-five thousand square feet of the Back Bay.

The discovery of the stakes initiated a controversy, which has waxed and waned all during the time this analysis was being carried on. Why were the stakes driven? Is the "structure" a fishweir, an oyster spat collector, a revetment, or the remains of piling upon which houses were built?

In 1913 the term "fishweir" was first applied, more or less tentatively, to account for the presence of stakes and wattles in the ancient Back Bay.[12] The validity of this explanation has never been challenged. In view of the many discussions of this problem, a number of modern fishweirs on the coast of Maine were investigated. This data is presented and discussed in Appendix I. The results of this discussion are, unfortunately, inconclusive. However, there appears to be sufficient evidence to justify the retention of the term Fishweir. In submitting the tentative hypothesis that the structure was used to catch fish, it must be emphasized that this idea lacks satisfactory proof, and, therefore, it is not permissible to apply interpretations of function to the argument. After all, the primary problem concerns the presence of man in the Boston Lowland at a time when certain ecological and geological conditions obtained. The discussion of the characteristics of his material culture awaits the discovery of further evidence of his industrial and economic life. It may be hoped that such evidence may soon come to light and that, in this event, it may be under circumstances which permit its association with the present discovery. Until more definite data are obtained, the term Fishweir can only be used as a convenient name for this assemblage of vertical stakes and horizontal brushwood.

[12] Davis, Edmund S., 1913, p. 44.

PART I

THE EXCAVATION OF THE FISHWEIR

FREDERICK JOHNSON

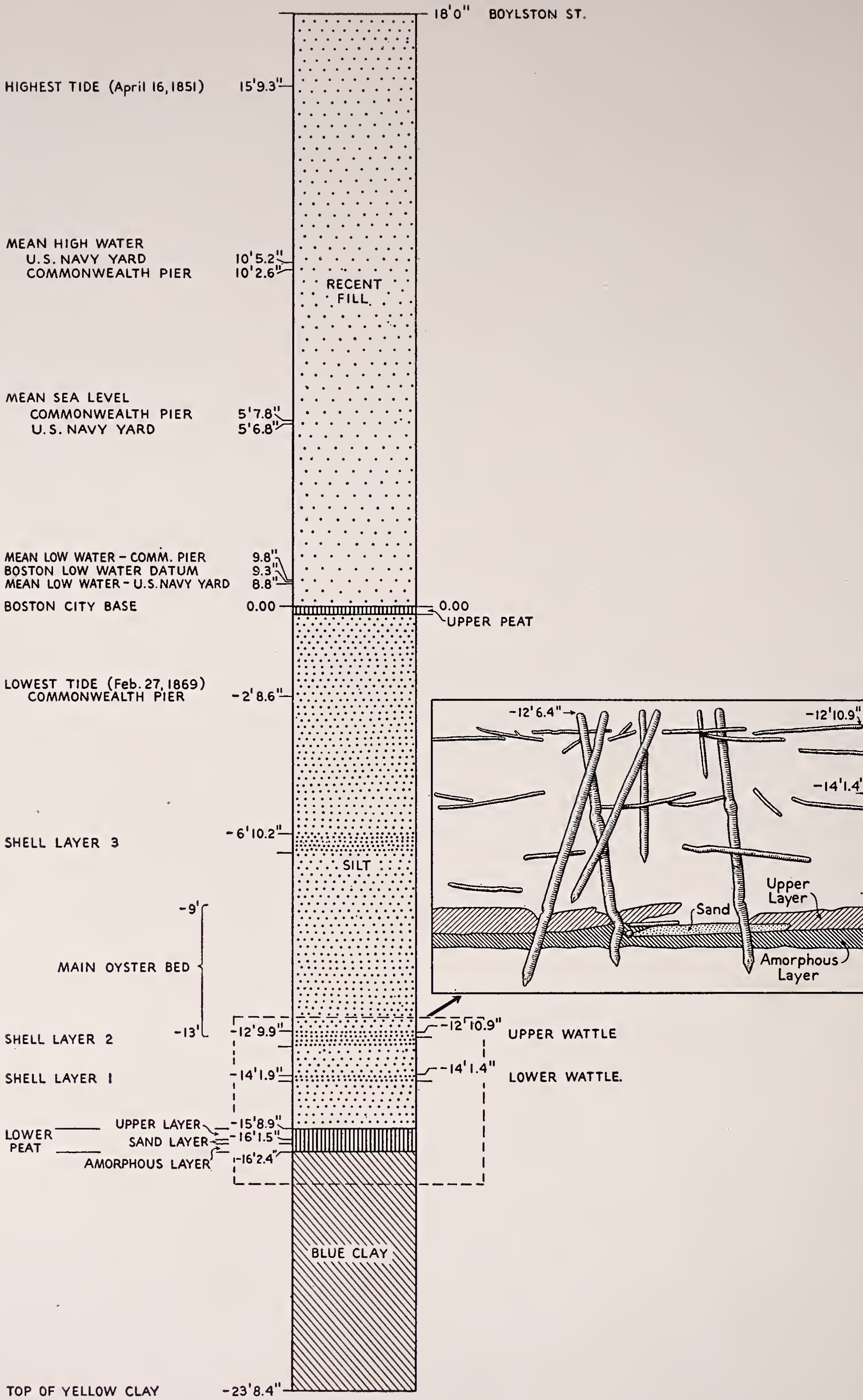

FIG. 2. Cross section of deposits in the neighborhood of the trench. Enlarged detail shows relation of stakes and wattles to deposits.

THE CROSS SECTION OF THE BUILDING EXCAVATION

ALL the data concerning the details of the location and construction of the Fishweir are referred to measurements and observations made in a trench eleven feet four inches east and west by eight feet four inches north and south (Figs. 3, 4; Pl. I). This trench was located in the southeast corner of the building excavation.[1] The excavation of the trench was begun by the construction company for the New England Mutual Life Insurance Company. The following data come from an extension of this hole in all directions.

When detailed work was begun, the surface of the vicinity of the trench sloped downward from $-11' 6''$ on the south to $-13'$ and below on the north.[2] The upper sections of the northernmost stakes had been cut off by the power shovel and could be seen on the exposed surface; but the tops of the southernmost stakes were in situ, being covered by at least one foot of undisturbed silt. Southward, beyond the limits of the trench, the slope continued upward to the level of Boylston Street. This slope was characteristic of all the walls of the building excavation, and the upper deposits, including Shell Layer 3, were exposed upon it. The lower part of the silt, the Lower Peat and the top of the blue clay were first exposed in the trench. Subsequently, building operations uncovered not only these layers, but penetrated the blue clay for varying distances.

THE RECENT FILL

Between 1856 and 1894[3] the level of the land in the region was raised by the addition of artificial fill (Fig. 2). Some eighteen feet of sand and gravel, containing a slight amount of rubbish, were added to the marshes, creeks and mud flats, which the early Colonial inhabitants of Boston named the Back Bay. This fill was dumped on the surface of the Upper Peat which now reposes at 0.00 Boston City Base.

The Walker and Rogers Buildings, formerly belonging to Massachusetts

[1] Compass directions refer to "Local North" which was arbitrarily located following the direction of the sides of the excavation. Thus, the back of the excavation on Newbury Street is the north wall; the Clarendon and Berkeley Street sides, the west and east walls respectively; the Boylston Street side is the south wall (Fig. 4).

[2] All vertical measurements are referred to the Plane of Reference called "Boston City Base." The relationship of this Plane to other important established Planes is indicated in Figure 2.

[3] Bruce, 1940.

Institute of Technology—the Walker Building of late having been used by Boston University—had been built upon this fill. These buildings rested upon piles which had been driven through the lower part of the fill and through the silt to the top of the Blue Clay.

THE UPPER PEAT

The top of the Upper Peat, located at 0.00 Boston City Base, was practically level (Figs. 2, 5). In the northwestern corner of the building excavation, the only place from which a sample of this peat was obtainable, it was four inches thick. Other records state that this layer was about two inches thick. The peat covered the entire area of the building excavation.[4]

THE SILT

The silt included various shell layers, the major portion of the wooden stakes and all the "wattling" which comprised the Fishweir (Fig. 2). In addition, many varieties of mollusks were discovered in this deposit. The silt was fine grained, containing varying amounts of sand, occasional pebbles, and, rarely, stones ranging up to some six inches in diameter. The upper layers of silt were slightly coarser than the lower layers.[5] The silt was practically impervious to water, but, when the surface was very wet, it became slick and very sticky. When freshly uncovered, it was sticky, being similar in consistency to putty. It could be cut with a trowel, but it could not be scraped or brushed. When dry, it became hard and brittle. In this state, it could not be cut, for it fractured into irregular, angular chunks.

THE SHELL LAYERS

Three shell layers were identified, at first tentatively, and finally with some certainty (Fig. 2). As a whole, these layers were concentrations, in the silt, of small pebbles, whole shells and shell fragments, rare fragments of vegetable material, varying amounts of sand and silt. Frequently, large numbers of mollusks, which had died in their natural position, were found either in a layer or just below it. The layers interrupted the progression of the silt deposit.

Shell Layer 3

This uppermost layer covered all the area exposed. On the north and east walls of the excavation, the upper surface was found at $-4' 6''$. In the center and also in the southern sections, it was measured at $-6' 10.2''$ (Fig. 2).

[4] L. S. Homer, Correspondence, 4/22/41. [5] P. 42.

This layer sloped downward toward the south and west (Fig. 5). The layer averaged seven inches thick, varying in thickness over its extent less than one inch.

Shell Layer 3 was composed of a large proportion of shell fragments and single valves mixed indiscriminately in the silt, which included a noticeable quantity of coarse sand and small pebbles. The latter were less than one quarter inch in diameter. Most of the whole shells were found in their natural position, i.e., they had not been disturbed after they died and the bivalves were found with both valves in their normal position. Bivalves in their natural position were found immediately below the main part of the layer. Frequently, numbers of these bivalves were concentrated in areas covering several square yards. Such concentrations were reminiscent of crowded conditions found below present day mud flats.

Shell Layer 2

This layer was found throughout the excavation. In the trench, the upper surface of this layer lay at $-12' \ 9.9''$ (Figs. 2, 5). The layer was six inches thick, exclusive of the molluscan shells lying immediately below. Seventy-five feet northwest of the trench, the surface of the layer was $-13' \ 6.9''$. It is a question whether this difference in depth, i.e., nearly ten inches in seventy-five feet, is sufficient evidence to suggest that the Shell Layer, throughout its extent, sloped downward toward the northwest. Such a difference might easily represent an uneven surface rather than a graded slope. Observation of this layer in other more distant parts of the excavation was difficult. On the north and west walls, this shell layer was less clearly marked because there were fewer fragments of shell and less sand than was encountered in the vicinity of the trench. The number of shells of mollusks which had died in situ was more nearly equal to their frequency of occurrence in the silt above and below the layer. Thus, while it was believed that the layer was at least twelve inches thick, it was impossible to be certain of any measurements. It did not seem wise to record depths arbitrarily under these conditions, and so it may be said, simply, that in the northwest the layer was present.

The Upper Wattle was clearly associated with this layer throughout the extent of the excavation. In the east, where the Upper Wattle was clearly separated from the Lower, it was included entirely within Shell Layer 2 (Fig. 2). In the western sections, it was not possible to separate the two layers of wattling. In this area, the upper parts of the wattling were found beneath the surface of Shell Layer 2, and the wattling extended downward to points below the bottom of the layer.

Shell Layer 1

In the test trench, the top of this layer was identified at $-14' \ 1.9''$ (Fig. 2). The layer was three inches thick. The layer appears to be associated with the upper parts of the Lower Wattle. In other sections of the excavation, no exact measurement could be made.

The layer was identified as a concentration of the shells of the smaller varieties of mollusks. Some of these were in their living position, but the majority were single valves and fragments. Fragments of barnacles appeared to be the most numerous of all the shells. The silt also included a very little fine sand of a size which was barely identifiable with the naked eye.

The distribution of this layer over the excavation followed the Lower Wattle. In places where the wattle was thin or absent, it was impossible to identify the layer with any degree of certainty. In the west, where the two layers of wattling could not be separated, Shell Layer 1 could not be identified as other than a few scattered shells. The most that can be said is that in these regions there was a noticeable increase in the quantity of shell material toward the bottom of the wattling. The surface of Shell Layer 1 was easily identifiable, wherever the top of the Lower Wattle was clearly marked. The bottom of this layer followed the bottom of the wattle. That is, where the wattle stopped abruptly, so did the Layer; where there were twigs and such between the main part of the wattle and the Lower Peat, the shells were fairly numerous, but not as common as in the layer itself. When this latter condition obtained, it may be said that Shell Layer 1 extended downward from its upper surface to the peat with the major concentration in the upper sections.

THE OYSTERS

Oyster shells were found distributed from immediately above the peat to $-3'6''$, or one foot or more above Shell Layer 3. The principal concentration of the shells was in a bed, the top of which appeared near $-9'$, and the bottom, four feet below at $-13'$, this has been called the "Main Oyster Bed" (Fig. 2). Above and below this bed, oyster shells were found either as isolated examples or in smaller groups. These extensions above and below the main bed were in reality part of the bed, for there was observed a sufficient number of cases where there was a continuous succession of shells attached one to the other from immediately above the peat to above Shell Layer 3.

By far the greatest majority of oysters stood vertically in the bed, i.e., they grew upward from the hinge. The bed was built up through the attachment of one oyster upon another into a formation resembling a tangled mass of rockweed. In localities where the shells were concentrated, they were,

more frequently than not, interlocked to such an extent that they had to be broken apart—a condition which increased the difficulty of securing complete specimens. By far the greatest majority of shells were attached to other oyster shells. There was, however, an estimated one per cent of shells which were free.

The vertical growth of the bed had been very irregular. In addition to the "ragged" upper and lower boundaries, there were places where the vertical growth had stopped for a while, the space being filled with silt. The upper boundary of this space would be covered over by horizontal extensions of shells from the sides. Thus, in some of the cross sections of the bed, there were places one to three feet thick which included nothing but silt.

The horizontal distribution of the oysters was nearly as irregular as the vertical. There were sections in the building excavation where from top to bottom, oysters were scarce. There were other sections where they were packed so tightly that they could not be removed until they were smashed. Very generally, it may be said that the greatest concentration existed in the eastern sections of the building excavation with lesser concentrations along the south and west sides. The least concentration was noted along the center of the north wall, extending less than half way across the building excavation in a southerly direction.

An estimated eighty to ninety per cent of the shells were the "cat-tongue" form, i.e., they were very long and narrow. These forms averaged about eight inches in length, and some two to three inches in width. The longest shell recorded was seventeen inches long and four inches wide. The narrowest shell was one inch wide by seven inches long. From these larger sizes, the oysters graded down to tiny shells which represented practically all but the very first stages of development. The relatively few rounded forms averaged some three inches in length by some two inches in width; the largest of these were not more than seven inches long and five inches wide.

The oyster bed began to accumulate very soon after the Lower Peat was covered with enough water to allow them to live. No actual record of contact between "living" oysters and the Lower Peat was made. However, occasional single valves were found resting on the surface of the peat and in the "holes" in the peat. Rarely, oysters were found attached to various types of debris located in the silt within a few inches of the peat. The bed developed from these first locations through the attachment of one oyster upon another. This process produced columnar clusters, the bottoms of which were located from six to fifteen feet apart. As the clusters "grew" vertically by the setting of one or more oysters on another they led up through the wattling of the Fishweir into the main bed. When the develop-

ment of the oyster bed reached the level of the Upper Wattle and Shell Layer 2, the quantity of oysters increased materially so that many new clusters began to appear and the general interlocking of extensions from the clusters took place. The closely packed main bed grew upward to approximately $-9'$, where it began to thin out. This resulted in the development out of the main bed of scattered clusters. These extended upward, usually to Shell Layer 3, with exceptions which extended further upward through this Layer to $-3'\ 6''$. From this distribution, it may be suggested that oysters began to live in the region after the peat was submerged. They reached their greatest development, especially in numbers, between $-13'$ and $-9'$. They practically disappeared by the time they had reached the level of $-3'$.

The oysters lived and increased during the period when the weir was in use. Shells were found attached to the Lower Wattle and also to the Upper Wattle. The discovery of shells upon which branches of the Upper Wattle rested, as well as shells attached to some of these branches, makes possible some speculation concerning their growth. It is possible that during the time the oyster bed was developing, the Upper and Lower Wattling was located in clear water. Thus, the vertical clusters made by the attachment of one oyster upon another "grew" upwards. In this way, oysters could develop beneath the Upper Wattle and still not be attached to it. Another idea is that the silt was being deposited during this period and that the vertical progress of the oyster bed developed with this deposition. Likewise, as the surface of the silt was built up, so was the wattling. Thus, the Upper Wattle may have been placed on top of some shells. Subsequent to this, oysters became established not only upon older shells but also were attached to the Upper Wattle. In some cases, individual shells were found attached to both the wattle and to another oyster. In other cases, an oyster might be attached to either the wattling or to a shell. In the latter instance, at the level of the wattling, the brush would be found surrounding the shells but free from them. It may be noted here that relatively few oysters were found attached to the stakes or the surrounding bark. Only in locations where the clusters developed among the stakes, were oysters found attached to them. There were, of course, sporadic instances where single oysters had set and remained upon a stake. The greatest majority of oysters were attached to other oysters. The significance of this is discussed in T. C. Nelson's study of the oysters.[6]

During the excavation of the trench, but one cluster of oysters was uncovered (Pl. II). This was investigated with considerable care. The mass of oysters consisted of a roughly cylindrical cluster some two feet in its hori-

[6] Cf. esp. pp. 52–56.

zontal diameter. The cluster extended obliquely downward in a southeasterly direction from the surface of the trench to a point corresponding with the Lower Wattle. The few oysters which lay horizontally were, with some exceptions, either attached to or located very close to the Upper Wattle.

The rare rounded forms were found between the Upper and Lower Wattle in the trench. This suggests that they were located in spots protected from the flow of water, perhaps by a combination of the wattling and the accumulation of other shells. Similar situations, in or above the weir, may account for the scattering of these forms throughout the excavation.

THE LOWER PEAT

The upper surface of the Lower Peat was inclined from $-15' 8.04''$ in the east to $-18' 10.56''$ in the west (Figs. 2, 5). The axis of the slope led downward in a direction slightly south of west. This sloping surface was interrupted by occasional depressions and hummocks, such irregularities being responsible for differences in the thickness of the bed. This bed may be divided vertically into three layers which are more or less distinct. These have been called Silty Peat, Upper Layer, and Amorphous Layer.

Silty Peat

The first layer has been called Silty Peat.[7] This was composed of silt in which was mixed small fibrous fragments of vegetable material. The fragments stood vertically in the silt and measured up to twelve inches or more in length. The variation in thickness and concentration of this layer was so great that even the most general statements are misleading. It may be suspected that this layer is due to the accumulation of silt in the grass and sedges growing on the peat. It is equally possible that this layer may have accumulated through accidents of deposition, that is, fragments of vegetable material floated or were washed about to be included in the first deposits of silt. However, this hardly explains the vertical position of the fragments. Since no definite measurements of this layer could be made, all depths of the peat were taken on the top of the Upper Layer, the layer described below.

The Upper Layer

The second layer, or that which has been called the Upper Layer (Fig. 2, Pl. III) was an allochthonous deposit composed of fragments of grasses and

[7] Reports on borings by Soil Mechanics Laboratory, Graduate School of Engineering, Harvard University.

sedges and their roots, together with other plant tissues, insect chitin, sponge spicules, spores, occasional small fishbones, diatoms, pollen, fungi and other organic remains, both structural and amorphous.[8] A small amount of silt was mixed in with these materials. This layer varied considerably in thickness, random measurements over the building excavation ranging from five and one half inches to eighteen inches. There were places where this layer of peat was extremely thin or missing. In such places, the Upper Layer seemed to be less compact than was the rule. In these sections, the layer included a large proportion of silt, and sometimes these places appeared to be an extension downward of the Silty Peat. Below such areas, which were never more than twenty feet in diameter, the Amorphous Layer was always to be found. Near the northeast corner of the building excavation, the Upper Layer contained relatively little silt, but it included a stump which has been identified as oak. Most of the stump was ripped up by the power shovel. A careful examination of the remains, including some roots in situ, led to the conclusion that the stump was not necessarily in its original location. The top of the stump and the ends of the spreading roots had no bark on them and were worn smooth. The whole thing was similar in appearance to water-logged stumps which may be found washed up on any shore today. The workmen said that several other similar stumps were removed from the peat in the southwestern parts of the excavation by the power shovels.

The Amorphous Layer

The third layer has been called the Amorphous Layer because of the character of its content. The organic matter, including plant tissue, was finely divided, having been subject to considerable decay. Fungus hyphae were noted during its examination, as well as some insect chitin, pollen, and rare diatoms. There was less silt in this layer than in the Upper Layer. This layer extended without interruption over the entire area of the building excavation. In spite of this separate description, this layer is intimately connected with the Peat which rests upon it. The thickness of this layer in the eastern sections of the building excavation varied between two and one quarter and three and one quarter inches (Fig. 2, Pl. III). A slightly greater thickness was observed but, unfortunately, not measured in the western and southwestern sections. It is estimated that nowhere would the thickness exceed six inches. Extending downward from the Amorphous Layer into the blue clay, for distances up to two feet, were remains of what were certainly roots, probably of the grasses and sedges which grew while the Upper Layer

[8] For further description of the contents of the Peat, cf. p. 69, p. 88.

PLATE I

General view of trench partly excavated. Most of Upper Wattle has been removed. Tops of stakes damaged by power shovels.

Plate II

Cluster of oysters just above Upper Wattle in trench. On left a stone rests upon the Upper Wattle.

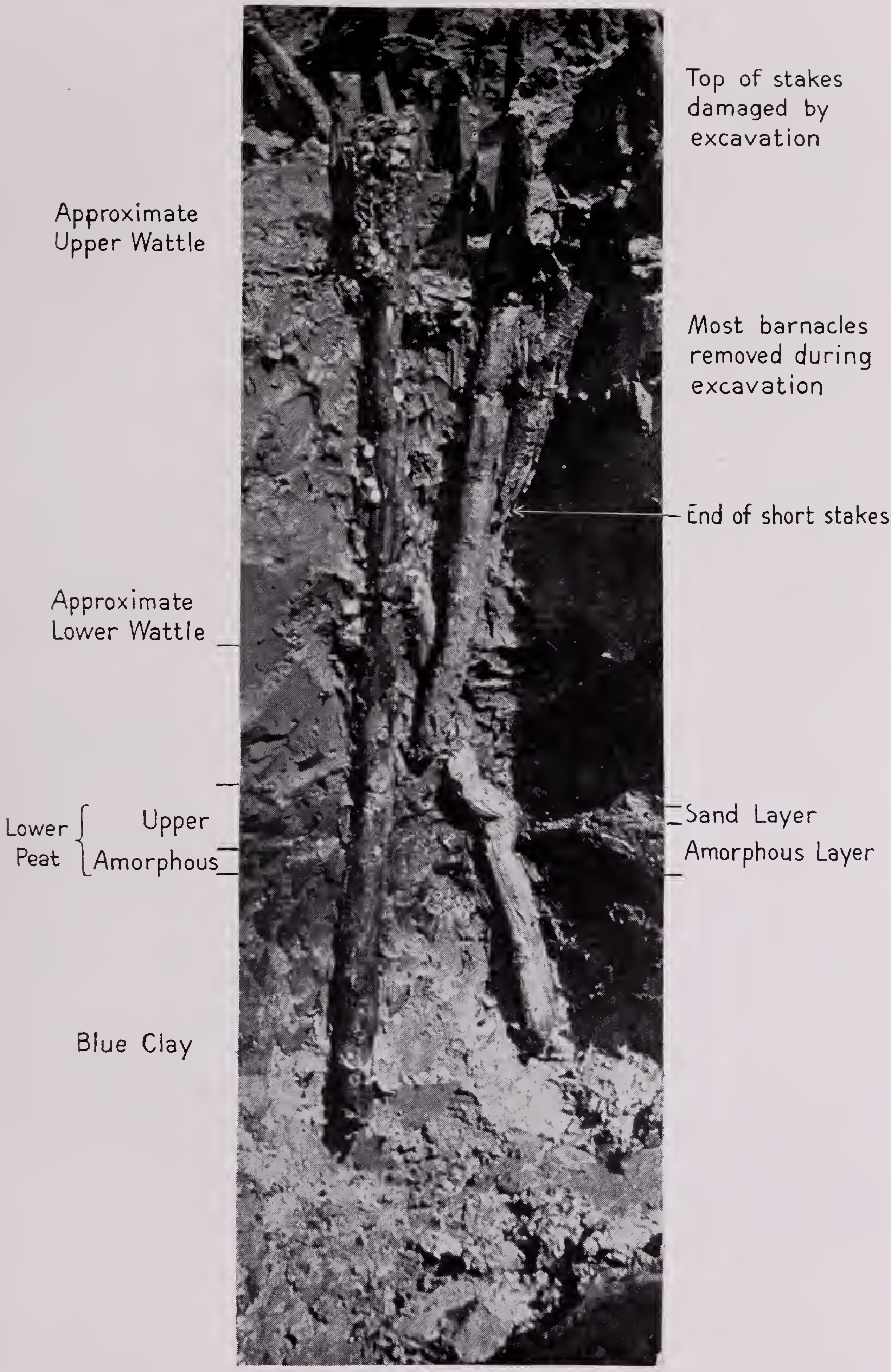

Plate III

A group of stakes exposed in trench. Marginal notes indicate various features of the deposits.

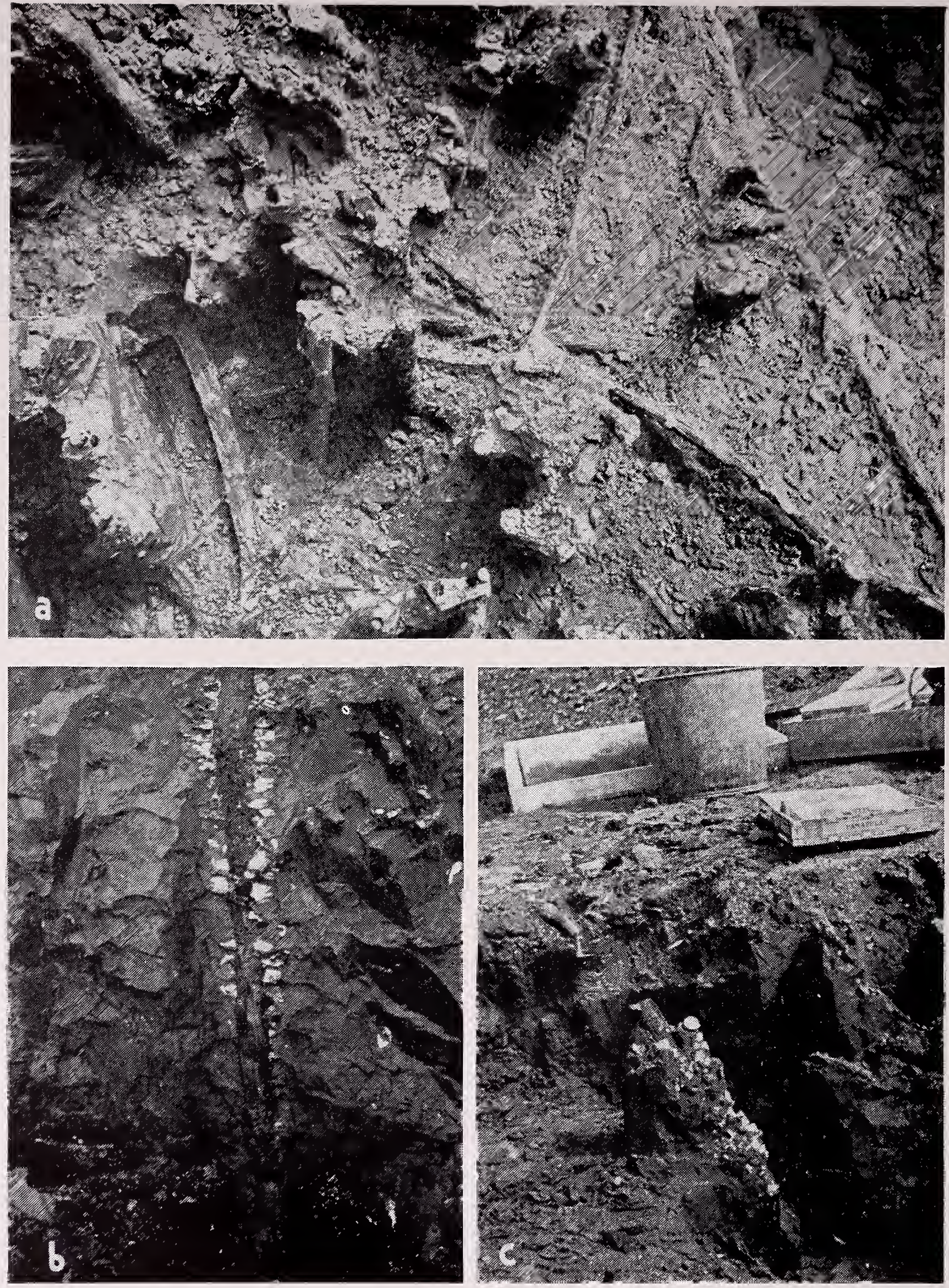

Plate IV

a. Section of Upper Wattle uncovered in trench. Ends of stakes damaged by power shovels. View from above.

b. Mold of stake removed from silt. Note barnacles remaining in silt on sides of stake.

c. Upper section of stake to show cluster of barnacles. Top of stake and adhering barnacles damaged by power shovel.

and the Amorphous Layer were accumulating. These roots, while occurring frequently, were not common enough to justify the identification of a "Clayey Peat Layer," as was done in the case of the "Silty Peat."

Sections where the Upper Layer was missing were not frequent in the peat deposit, but they were numerous enough to suggest that they were

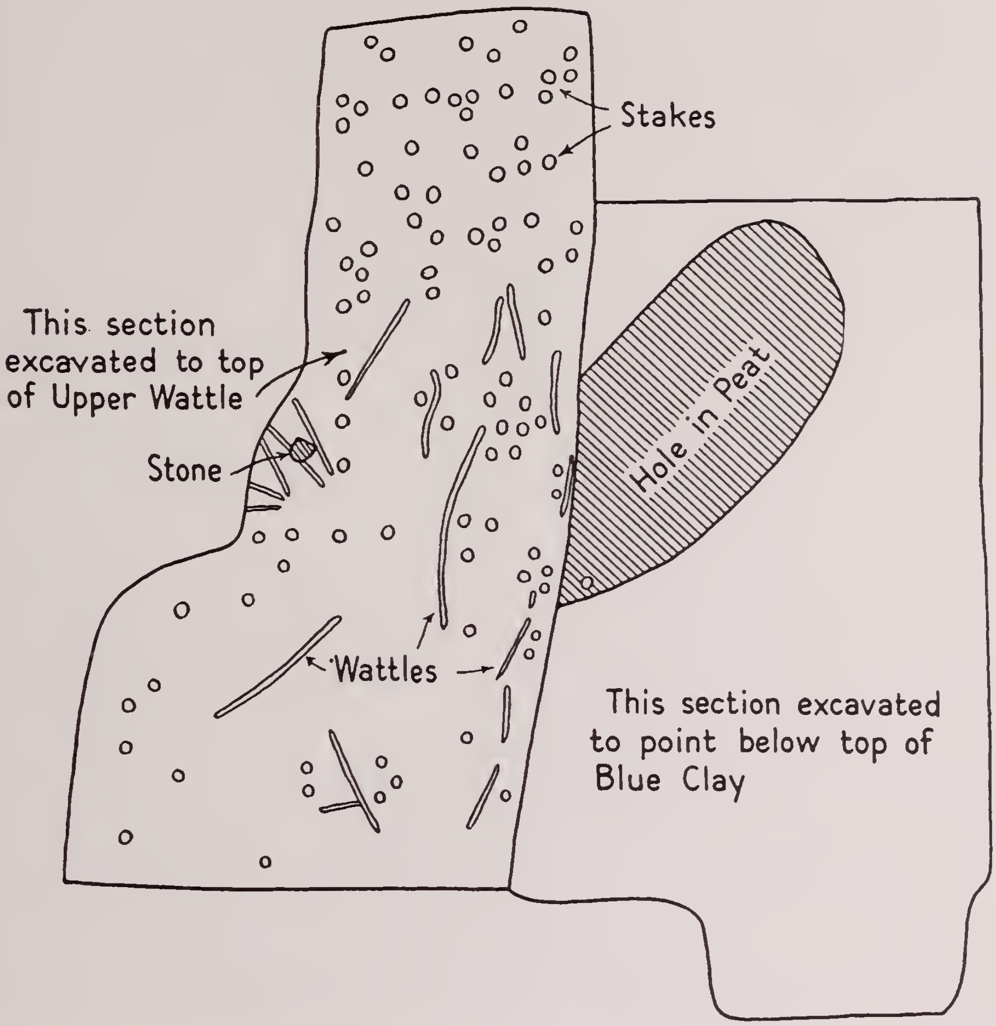

FIG. 3. Plan of trench showing approximate distribution of stakes and some of the Upper Wattle in the eastern sections.

characteristic of it. All of the "holes" in the Upper Layer which were seen were identical, with the exception that the Sand Layers[9] at the bottom of these holes varied in concentration and thickness. A typical one of these holes, discovered in the trench, is described below.

In working out the surface of the Upper Layer in the trench, it was discovered that in one place the Silty Peat extended downward below the usual

[9] Sand Layers were only found in places where the Upper Layer was missing. They did not separate the Upper Layer from the Amorphous Layer.

level of this surface (Fig. 2, detail drawing). Eventually, evidence of what had been a hole in the peat, roughly oval in plan, was laid bare (Fig. 3). When the hole was cleared, a layer of sand was revealed at the bottom. Mixed in the sand were small pebbles, broken shells of various mollusks, single valves of oysters, and silt. The Sand Layer was two inches thick in its deepest place and its surface lay four inches below the top of the peat (Fig. 2, detail). While the Silty Peat lay directly upon the Sand Layer over most of its area, the edges were usually covered with the Upper Layer. The Sand Layer extended beneath the peat for distances varying up to nine inches. In some cases a very thin layer of silt had penetrated the edges to separate the horizontal extension of the Sand Layer from the overlying peat.

Lying in direct contact with the surface of the Sand Layer were several branches and twigs (Fig. 2, detail). In appearance these were identical with those of the wattling in the Fishweir. It is interesting to note that in some cases these twigs were included in the thin layer of silt which extended beneath the peat. In one case (Fig. 2, detail), one end of a branch was completely surrounded by peat and in another the branches lay on the Amorphous Layer at the very edge of the Sand Layer.

The Sand Layer rested upon the Amorphous Layer and there was no evidence to indicate that the latter had been depressed. The edge of the Sand Layer feathered out to nothing and in several places a thin layer of peat separated the edge of the Sand Layer from the Amorphous Layer.

It is impossible to find an acceptable explanation for holes such as that just described. At first it was believed that they may have been the remains of salt pans but this hypothesis is not satisfactory. Fishweir stakes had been driven through the holes, but it is impossible to say whether their presence caused currents to scour out the holes or not. The stakes may have had nothing to do with their formation, having been driven after the holes were in existence.

THE BLUE CLAY

The surface of the blue clay was parallel to the sloping surface of the peat (Fig. 5). In the trench the surface of the blue clay was located at $-16' 2.4''$ (Fig. 2).

The blue clay was the upper layer of a deposit of clay about seventy feet thick. The deposit was composed of a layer of blue clay some seven feet thick lying upon a layer of clay which had a yellowish tinge. The yellow clay averaged five feet thick. This upper layer, i.e., the blue clay and the clay which had a yellowish tinge, was much harder than the clay below it. The lower layers were composed of a soft blue clay, and they were fairly uniform

in character, although throughout its depth there were sand seams, some of which were water bearing. It is believed that this blue clay, and also the yellow, were of glacial origin. It has also been suggested that the yellowish tinge of some of the clay was due to oxidation of the iron at some period when it was exposed. Further discussion of this layer has been relegated to the section on the geology of the region.

Below the blue clay there was a layer, frequently called hardpan, which was some thirty-five feet thick. The hard pan, a cemented mixture of clay and gravel, said to be of glacial origin, lay upon slate rock.

THE FISHWEIR

THE remains of the Fishweir were found over the entire bottom of the building excavation, an area of about 65,000 square feet (Fig. 4). In no place was there any indication that a margin of the structure had been uncovered, for concentrations of stakes were followed into all four walls of the excavation. The stakes reported in 1913 were found about one hundred feet southeast of the trench.[10] In view of the great extent of the structure in the building excavation, it is a safe assumption that these stakes were part of it. Thus, the structure must have run for some distance to the east and south beneath Boylston Street and the property of the Boston Society of Natural History. Also it probably extended to the north and west.

THE PLAN OF THE FISHWEIR

We are extremely grateful to Messrs. Pitcher and Homer of the Turner Construction Company for the plan of the distribution of the stakes and other features on the lot. Data from the field notes have been added to the original plan to form the basis of Figure 4. This plan was developed while following the paths of the power shovels over a period of several months. It was impractical to attempt the location of every stake and every detail, and so this plan shows the distribution of the major features which were observed.

In building the weir the aborigines drove stakes vertically into the bottom of the ancient Back Bay and laid brush, here called wattling, horizontally among them. Plate III shows several stakes and Plate IV*a* shows a section of the Upper Wattle. Stakes were driven in "Walls" (Fig. 4, 1–6), and in "Areas of Concentration" (Fig. 4, A–F). Beyond the locations indicated, stakes were also numerous, but, as they were not close together, their distribution did not appear to be significant.

The six Walls noted were determined by locating the boundaries of areas in which there were several stakes per square foot. The Walls varied in width from two feet to about ten feet. Three of the Walls ran north and south across the lot, their ends disappearing into the sides of the excavation (Fig. 4, 2–4). A fourth Wall ran into the north side of the excavation, but its south end was found some thirty-two feet from the south side of the

[10] Information regarding the construction of the Boylston Street Subway supplied by Mr. Wilbur Davis, Chief Engineer of the City of Boston.

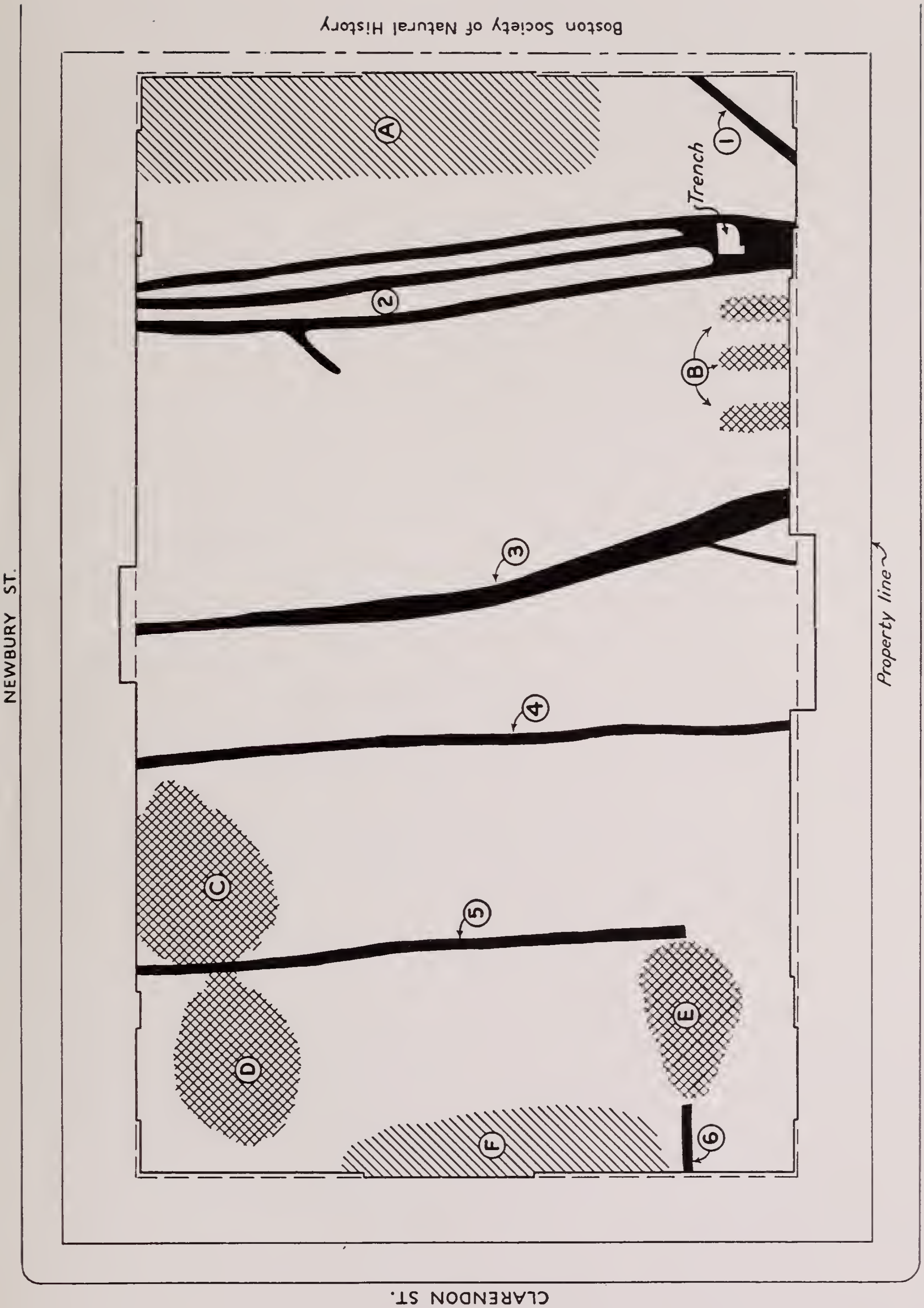

FIG. 4. Plan of principal concentrations of stakes in the building excavation. Adapted from a plan by the Turner Construction Company. For description see pp. 24–25.

excavation. It is difficult to say whether this ended abruptly or whether it originally continued through the scattered stakes of Area E.

The peculiar distribution of the stakes in Wall number 2 is impossible to explain. Whether the three lines represent replacements of a single Wall or whether this was some specialized section of the structure may never be known.

While what appear to be the principle Walls run north and south, there are several others which run in different directions. For example, the very clearly defined Wall in the southeastern corner (Fig. 4, 1) runs northeast and southwest. Appendages of Walls 2 and 3 also run in this direction. Wall number 6 runs directly west out of Area E. It is possible that these Walls are indications that the structure became more complicated to the south of the building excavation.

But little may be said concerning the Areas of Concentration. Their boundaries were by no means distinct, and no clear system of arrangement of the stakes could be seen. The stakes in the Areas lettered A and F were thinly scattered and there is perhaps slight justification for recording them. There is some slight possibility that these concentrations are an indication of the presence of Walls immediately east and west of the side of the excavation. Concerning Area B, the evidence is not conclusive. The stakes were first discovered in this area, and some believe that at least three Walls were to be seen. However, these stakes were badly damaged by the power shovels, and they were removed before there was opportunity to check the observation.

Areas C, D, and E were characterized by a heavy concentration of stakes. These were as numerous, per unit area, as they were in any of the most clearly defined sections of the Walls.

THE STAKES

The stakes had been trimmed of branches and one end had been crudely sharpened (Pl. III, V). They were usually driven butt end downward, but approximately one-fifth of the stakes had been sharpened at the smaller end and driven upside down.[11] Repeatedly it was noted that four to eight stakes were driven in a group which occupied about one square foot. Since many of the stakes were neither straight nor exactly perpendicular, the lower ends spread over a much larger area (Pl. III). Frequently, but not in a sufficient number of cases to permit the formulation of a general rule, each of these

[11] Opinions vary concerning the number of stakes which were sharpened on the butt end. The Field Notes are very clear in this respect, but the construction engineers say that the majority of stakes had been sharpened on the smaller end.

groups would be composed of several stakes about one inch in diameter and one or two larger ones, some two, three or rarely four inches in diameter. Otherwise, the groups were made up of stakes of all sizes apparently selected at random. No attempt was made to identify the types of wood in each group. The centers of these groups were from one to several feet apart but they did not appear in any regular order. However, they occurred most commonly in the Walls shown on the plan (Fig. 4). In addition to the groups of stakes, there was a multitude of single stakes. These were stakes of all sizes, ranging from one to four inches in diameter, and they were most numerous in the Walls or Areas as indicated in Figure 4. In addition, single stakes were found in disturbing frequency outside these areas. Estimates of the numbers vary from five thousand to one hundred thousand. The construction company engineers estimate between ten and twenty thousand. Observations in the trench and over other parts of the building excavation indicate that in many sections there was more than one stake per square foot or, for the whole area, a possible maximum of sixty-five thousand. The actual number of stakes is only of passing interest, the point being that there were stakes in sufficient numbers to indicate the presence of a structure of incredible size and proportions.

THE WATTLING

The wattling was simply a mass of branches and shrubs which had been crowded down among the stakes. Occasionally a branch which had been riven into several pieces was included in this brushwood (Pl. IV, *a*, lower left hand corner). During the excavation there were rare instances when the relation of the wattling to the stakes suggested weaving. However, it was discovered that such supposed weaving never involved more than three vertical stakes and that either or both ends of the branches wandered off in a hit-or-miss fashion among several other stakes; therefore, there was no real evidence of the weaving of brush among the stakes. Careful and continuous searching failed to disclose any evidence that the wattling had been tied to or around the stakes. The scars interpreted as evidence of tying by Shimer and Willoughby[12] have been found to be, without exception, fractures and failures resulting from compression.

In the trench, brush was concentrated in two levels (Fig. 2). The Upper Wattle was made up of branches and brush usually one-half inch in diameter or less, but with occasional branches which were about one inch in diameter. For the most part, the branches were laid northwest and southeast with the

[12] Shimer, 1918; Willoughby, 1927, 1932.

butts to the southeast. The twigs extended from these branches in every direction, but most commonly to the sides and downward. The upper surface of the Upper Wattle appeared relatively smooth, being characterized by horizontal branches and brush. The layer averaged about two inches in thickness. In a number of places sticks or twigs extended downward for several inches. Where the Upper and Lower Wattle were identified, the twigs of the Upper did not overlap the twigs which projected upward from the Lower Wattle. The brush of the Upper Wattle was generally included within Shell Layer 2, the top of the wattle being covered with about one inch of this Shell Layer. Where Shell Layer 2 was exceptionally thin, or the surface of the wattle uneven, the Upper Wattle lay an inch or so below it.

In the trench, some oyster shells and one stone, six inches in diameter, were resting on the Upper Wattle. In view of the possibility that the stone was rafted in by the ice, little or no significance may be attached to its location.

The top of the Lower Wattle appeared in the trench one foot two and one half inches below the top of the Upper Wattle (Fig. 2). This layer was essentially the same as the Upper, except that its surface was more irregular. The branches lay in a general northwest-southeasterly direction, but the twigs extended haphazardly in all directions.

In the trench, this wattle was made up of a single layer of brush which did not seem to be as closely laid as the Upper Wattle; in fact, in the southwestern end of the trench, the branches were found separated by distances varying between six and twelve inches. On the other hand, there were places where several branches had been piled one on top of the other. In these places the Lower Wattle was three inches or more in thickness.

The thickness mentioned above refers to a concentration of brush resembling that of the Upper Wattle. Beneath the Lower Wattle, twigs and branches were found, sometimes approaching in quantity the amount in the layer itself. More frequently, however, the brush appeared as isolated short pieces. Some isolated sticks were in direct contact with the peat. Some pieces were found in the hole in the Upper Layer (Fig. 2). In two instances branches were found beneath the Upper Layer. Since there is some possibility that these branches were not connected with the wattling or, if they were, they may have been covered by a slumping of the edge of the hole, their location may be of little significance.

In following the horizontal distribution of the wattle layers over the area of the building excavation, it was found that, while the conditions discovered in the trench were typical, there were important variations in the relationship of the Upper to the Lower Wattle. In some sections the brush

in both layers was less common than it was in others. There were also sections where either the Upper or Lower Wattle, sometimes both, were completely absent. Generally speaking, either or both layers of wattle were associated with the Walls. There were, however, many exceptions to this rule, for, in some places there was no wattling in the Walls, in others either the Upper or Lower Layer was missing. Sometimes wattling of either one or both layers was discovered in the Areas of Concentration or lying among the more widely spaced single stakes which were found between the Walls.

The Upper and Lower Wattle were quite distinct in the eastern sections of the building excavation. They were separated by a layer of silt which contained a few flecks of shell and, rarely, shells of mollusks in their living position. To the west the two layers of wattle were by no means as distinct. The brush was not always concentrated in layers, but more usually, it was scattered through the silt from the upper surface of the wattling to a point roughly two feet below.

Where it could be measured, the levels of the upper surfaces of both layers of wattling varied but a few inches. They may be considered as lying horizontally over the whole area. The association of the Upper Wattle with Shell Layer 2 was quite clear in the eastern section. In the west, definite determinations could not be made because the Upper and Lower Wattle could not be separated and because Shell Layer 2 was less distinct. Similar difficulties were encountered in following the association of Shell Layer 1 and the Lower Wattle. Generally, Shell Layer 1 was present in places where the Lower Wattle could be identified. However, there were sections where either Shell Layer 1 or the Lower Wattle appeared alone.

THE RELATION OF THE FISHWEIR TO THE DEPOSITS

In the trench, the tops of the stakes were discovered in the silt at −12′ 6.4″ (Fig. 2, detail). Within a radius of approximately one hundred feet of the trench the depth of the tops of the stakes varied less than one inch. In the northern, western, and central sections of the building excavation, the tops of the stakes were located at various levels between −12′ 6″ and −13′ 5.1″.[13] The tops of the stakes not varying in height more than eleven inches over an area of 65,000 square feet cannot be ascribed purely to accident. It must be concluded that their location, at this depth, is significant.

The levels of Shell Layer 2, the Upper Wattle, and the tops of the stakes were, in general, parallel (Fig. 5). However, there were exceptions, that is,

[13] Unfortunately, no precise information is in existence which will locate the undamaged tops of the stakes found in 1913.

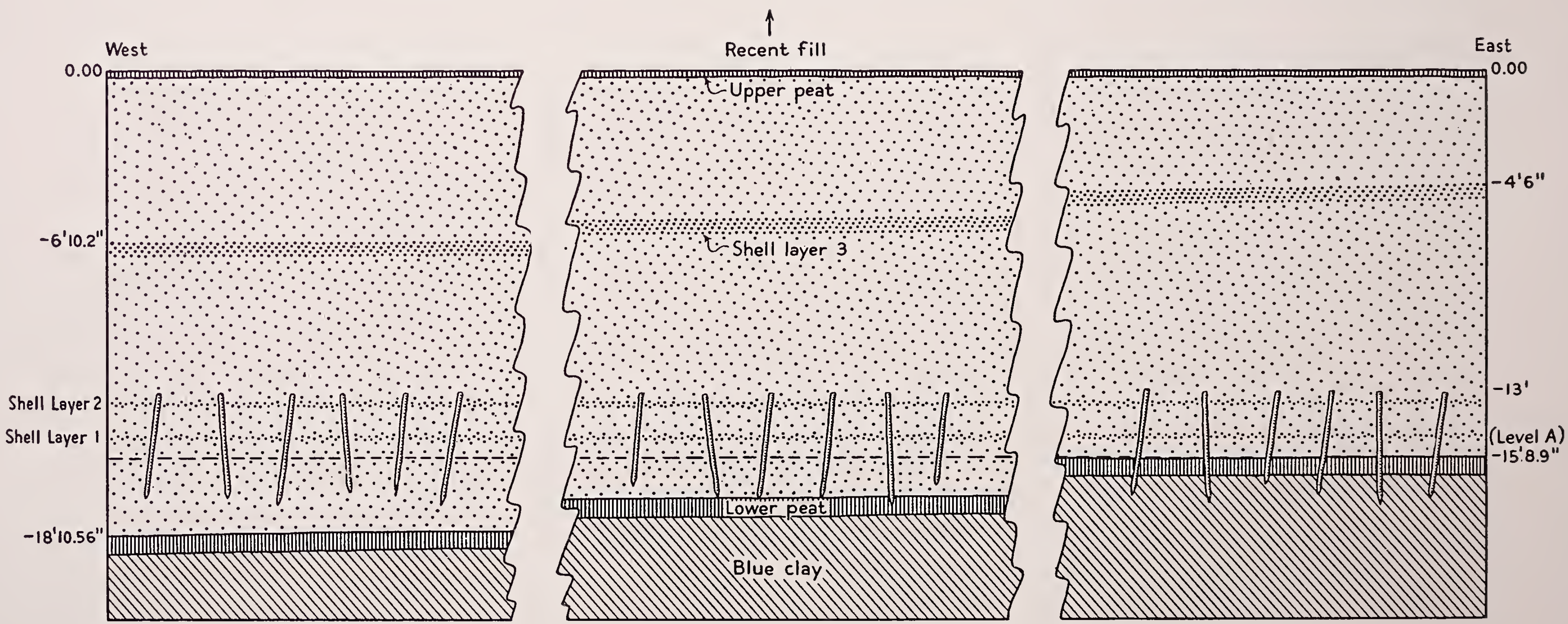

FIG. 5. Diagrammatic east to west cross section of the building excavation. For description see pp. 29–32.

variations in depths at different locations were not always consistent. In spite of these variations, the relationship of these levels did not change. The tops of the stakes always projected slightly above Shell Layer 2. This relationship suggests some association between Shell Layer 2 and the tops of the stakes; but the variations of both necessitate some caution in interpreting the significance of this relationship.

The bottoms, or sharpened ends, of the stakes were found at many levels. The highest recorded was −13′ 10.6″ and the deepest was −17′ 9.4″. In the easterly sections of the building excavation, the longest stakes had been driven through the peat into the blue clay (Fig. 5). The ends of shorter stakes were discovered in the peat, on the surface of the peat, and at varying depths in the silt. The ends of the shortest stakes were located in the silt between the Upper and Lower Wattle (Fig. 2, detail).

In the southern and western sections, where the surface of the Lower Peat was at its deepest point, the ends of the longest stakes were found in the silt above the peat[14]. (Fig. 5). The one or two extraordinarily long stakes which did enter the peat were located to the north and west in places where the peat was slightly higher than it was in the southwesterly corner. The shorter stakes, observed in the southern and western sections, ended at levels which were similar to those measured in the east. These ends were found among wattling which was a combination of the Upper and Lower Layers. The discovery that a considerable quantity of wattling lay in the silt below the ends of the shorter stakes is a significant fact which will be discussed below. The relationship of the wattling to the longer stakes in these sections was analogous to that noted in the neighborhood of the trench.

In working out the relationship between the stakes and the deposits which contained them, the distribution of the barnacles appears to have some significance. Isolated, single barnacles and also small clusters were found infrequently on the wattling, but many of the stakes were encrusted with them (Pl. IV, *b*, *c*). *Balanus eburneus* Gould was the only form found among the many which were collected and identified.[15] The majority were very large ones, many being as large or larger than those reported by Pilsbry.[16] The suggestion is, that there existed here a mature colony living under optimal conditions.[17]

In some cases the encrustation of barnacles on the stakes was made up of two, if not three, layers which completely covered the wood (Pl. IV, *c*). All

[14] Information also from L. S. Homer, Correspondence.

[15] Identifications by Dr. Charles Blake and Dr. Fennor Chase.

[16] Pilsbry, 1916, p. 83 et. seq. [17] Pp. 65–66.

stakes in the eastern sections of the building excavation, which supported such growths, had been driven through the peat into the blue clay. The encrustations ran down the stakes usually to the peat or within a very few inches of it. It was noted that the encrustation was always greater near the tops of the stakes than it was near the peat; in fact, double layers were not observed near the Peat, and frequently, at this level, the barnacles had not set close together on the wood.

Variations in the setting of barnacles on the stakes seem to have occurred, for some of the stakes which penetrated into the blue clay supported only a few barnacles, and these were not always found below the top of the Lower Wattle. However, none of the longer stakes were completely free from barnacles. It was observed that, without exception, the shorter stakes supported but a few barnacles and that the shortest stakes which ended between the Upper and Lower Wattle supported no barnacles at all. These observations were made with great care in the trench and immediate vicinity. Random observations in the central and western sections of the building excavation were made, but, unfortunately, in less detail. These observations indicate that barnacles set at the same levels over the whole area of the building excavation.

Figure 5 has been prepared to illustrate the preceding discussion. In this diagram, the east, center and west sections of the building excavation have been represented. Only the longer stakes have been included. The location of the lower ends in relation to the sloping peat bed may be seen. The fact that oysters and barnacles had been living at a level which is now about −15′ 8.9″ suggests that Level A, whatever its original relation to mean low water, was the bottom of the Back Bay when the first stakes were driven. If the fact that levels of the upper and lower ends of the stakes were horizontal and that the longest stakes were evenly distributed over the site is significant, it appears that the bottom of the Bay, marked by Level A, was also level. It is also true that the surface of the bottom of the Bay was peat in the east and silt overlying the peat in the west. Only exceptionally long stakes could have been driven into the peat in the western sections where, due to its pitch, it lay several feet below Level A.

The varying depths of the lower ends of the stakes and the presence of two layers of wattling strongly suggest that the weir had been used, added to, and repaired over a period of time, which also saw a silting up of the bottom of the bay. As the silt accumulated it covered up the lower parts of the weir, and, to compensate for this, more stakes and wattling were added to the newly deposited, higher levels.

Very few of the facts which might explain in detail this process of building

up the weir came to light during the excavation. The reason for this may lie in the nature of the construction. None of the stakes were attached one to the other, nor was the wattling attached to the stakes. Even the most careful untangling of the brush, especially in the trench, failed to show any direct association between the stakes themselves or between the stakes and wattles, except in so far as relative position is significant. The difficulty extends further than this, for observations during operations in the building excavation failed to produce any facts which would demonstrate an association between two or more of the Walls drawn on the plan (Fig. 4). Occasionally, wattling appeared to extend from one Wall to another, but difficulties surrounding the uncovering of large areas made definite determination of this point impossible. All the Walls include stakes of various lengths, as do the Areas of Concentration. The numbers of stakes of different length appeared to be of little significance and only brief test counts were made. What may be suggested is that the longer stakes, say those ending at $-16'$ and below, were probably the first ones driven and that they were associated with the Lower Wattle in the east or with the lower part of the wattle in the west. It seems quite probable that because of the location of barnacles and, to a more limited extent, the level of the oysters, these stakes projected upward into clear water, which ran on Level A (Fig. 5). That Level A may well have been below mean low water seems certain, for *Balanus eburneus* does not grow above this level. The shorter stakes were certainly associated with the Upper Wattle. They could not have been driven until sufficient silt had accumulated, not only to cover the Lower Wattle, but to reach at least the lower sections of the Upper Wattle. The fact that no barnacles were found on these shorter stakes is not conclusive, but it does suggest that the ends of these stakes were covered with silt or, in other words, that they had been driven into the silt from a surface which may have been that upon which the Upper Wattle rested.

There is no way to determine whether the east end or the west end of the weir was built first, or whether the whole structure was in use at one time. The fact that in the west there is a continuous deposit of wattling from the bottom to the top suggests that this end of the weir was in more or less continuous use. The presence in the east of the Upper and Lower Wattle, separated by a sterile layer of silt, would indicate that, for a time, this section of the weir was not in use and that, following this period of disuse, it was rebuilt and kept up until the whole thing was abandoned.

It has been shown that the tops of the stakes were found at depths the range of which included Shell Layer 2. It has also been stated that the difference between the highest and lowest top probably represents the de-

velopment of a single level. The location of the lower ends of the stakes, on the other hand, appears to indicate that there was a succession of levels. In support of this statement it may be pointed out that stakes, the tops of which were at different depths, were evenly distributed over the building excavation, there being no section where one particular depth was most common. Furthermore, there seemed to be no correlation between the length of the stakes and the location of the tops. In other words, short stakes were found with their tops ranging between $-12' \, 6.4''$ and $-13' \, 5.1''$, the same range as that in which the tops of the long stakes occurred.

Examination of numerous tops of the stakes from many sections of the building excavation led to the conclusion that these ends were not the original ones. Without exception, the tops had been either worn smooth or, more rarely, broken off (Pl. V, *c–f*). Frequently, but not always, the deeper ends, i.e., those about $-13'$, were the broken ones. With the exception of these, the tops displayed the smooth, irregularly worn surface that any nearly vertical stick or pile acquires when eroded off in the sea. The ends of the broken stakes were irregular, but the edges and points of the fractures had been worn smooth. The tops of a few of the stakes were so irregular that it was impossible to determine whether they had been broken or not.

Bailey and Barghoorn have concluded, "It is evident . . . that the stakes and wattles must have remained submerged since they were placed in the weir." Concerning the tops of the stakes, the same authors say, "It is significant, in addition, that the much eroded upper ends of the stakes show no evidence of decomposition and disintegration by fungi."[18] This data indicates that the tops of the stakes represent some level which has always been below the high water mark.

The tops of a few stakes exhibited the borings of *Bankia gouldi*. The remains of borings are to be found in stakes illustrated (Plate V, *c* and *f*). The borings were often but a few inches deep and the tubes were either missing or very fragmentary. Concerning the presence of this marine borer, Clapp says, "*Bankia gouldi* frequently enters timber at the mud line and drills downward. All of the tube may therefore be below the mud line excepting the extreme posterior syphon end. Destruction by Crustacea will then expose that portion of the tube above the mud line."[19] Actually, the borer may enter the wood at any place between the mud line and mean low water. In many of the longer stakes, especially those which penetrated the peat, the tubes of *Bankia gouldi* were complete and undamaged by erosion. Thus, the uppermost natural openings of the posterior syphons were intact,

[18] Pp. 87. [19] William Clapp, correspondence, 10/25/40, 1/21/41.

Plate V

Photographs of sections of preserved stakes.

a, *b*. Two complete stakes.

c, *d*, *e*, *f*. Tops of four stakes.

h, *i*, *j*, *k*, *m*. Sharpened lower ends of stakes.

l. Burned lower end of stake. This was the only end of this type seen. It is impossible to determine whether the stake had been burned purposely or accidentally.

g. One example of compression failure. Other examples may be seen in *a*, *b*, *e*, *h*, *i*, and *j*.

but, unfortunately, no measurements of the level of these openings were made. It is impossible to determine any relationship between the complete remains of borers and existing levels in the deposit. In some of the long stakes, the tubes, which had been exposed by the erosion of the top, were twelve to twenty inches long indicating that the stakes had been eroded off near the place where the borer had entered the stakes. Since the holes in the tops of the stakes were not the natural openings which *Bankia gouldi* makes for itself, they were uncovered after the borers had become established.

In summarizing this information it may be said that the stakes, particularly those exhibiting sections of borer holes, were originally longer and that they have been cut off above the mud line. In addition, the absence of fungi in the tops of the stakes indicates that they were cut off below the high water mark.

There is additional evidence that originally the stakes were longer. One stake was cut off where a compression ridge and fracture had occurred (Pl. V, *d*). Also some compression ridges were found very close to the tops of the stakes. Since compression ridges were formed beneath the surface during the consolidation of the deposit they were formed before the stake was cut off. This is particularly true of ridges which are very close to the tops of the stakes; unfortunately, only one of these was examined with great care. Once the fracturing had taken place, the upper section of the stake could have been pulled out of the silt by ice or any other agent. This would have left a stake top with a more or less "fresh" break; the edges would not have been smoothed down had they been continually covered with silt. A more likely explanation is that the upper section of the stake was removed through the lowering, by scour, of the mud line.

Several theories have been advanced to explain the location and characteristics of the stake tops. In one case it has been thought that, preceding the scouring, ice cut off the stakes at one level. An objection to this theory is that it must be assumed that no ice interfered with the weir until proper conditions developed along the level of the tops of the stakes. Or again, it would be necessary to assume that the ice appeared only during one period. If the proof that the weir was used during a period when there was some submergence and some silting is acceptable, it would be expected that the stakes would have been cut off on succeeding levels, and there would be a rather definite correlation between the depths of the bottoms and the location of the tops of the stakes. That is to say, the lower ends of the stakes which were driven first would be the deepest and these would have been cut off the earliest by the ice, with the result that the stakes with the deepest

lower ends would have their upper ends at the deepest locations. Such was not the case. It may be argued that, since the amount of submergence during the time the weir was used was less than the mean rise and fall of the tide, the tops may be the result of ice action in the intertidal zone. Even in this case a greater variation in the depth of the tops of the stakes would be expected. It seems that the evidence for and against the theory of ice action is entirely circumstantial.

It has been suggested that at some time, after the weir had been abandoned and the stakes somewhat weakened, an unusually violent storm raged over the area and broke off all the stakes. Such storms, and accompanying unusual high tides, have occurred during the colonial history of Boston. On several occasions the tide has been known to flood the Neck completely and raise havoc with the city.[20] However, if, as seems certain, the Fishweir was in use when sea level was lower, the topography of the area was quite different; thus, the influences of storms would possibly be modified. In addition, before accepting this theory completely, it may be asked if, during a storm, all the stakes would snap off at the same level. Then, too, it would be expected that some of the stakes would not break off, but, rather, that they would bend over and eventually become imbedded in the silt. There were occasional stakes whose angle might be accounted for in this way, but they were far too few to be used as proof that some catastrophe leveled the whole weir. It seems possible only to suggest that some particularly violent storm may have completed the work of other agents. Plate XIII,*a* shows the effects of a storm on a fishweir in Maine. From this illustration it appears that the effect of storms, though numerous, are not destructive enough to produce the situation discovered in the Back Bay.

It seems incredible that no evidence of the presence of boring Crustacea is to be found on the stakes. There is no apparent reason why *Limnoria*, *Chelura*, or other forms, should not have been common in the remains of the Fishweir. If the stakes were covered with water, as the barnacles on them would indicate, the borings of Crustacea should be found in many places on the stakes. The only possibility is that the organisms lived only in the bark, which unfortunately could not be preserved for examination. With this absence of evidence, it is rash to assume that the stakes were weakened by Crustacea or any other organism at any point above the present tops. However, it is possible that evidence of organisms which may have cut off the stakes may have been removed by the scouring of the tops.

If the discussion is restricted to the available facts, the only cutting agent which can be identified is the scouring action which can take place along a

[20] Perley, 1891.

mud line. In a discussion of the tops of the stakes, Clapp has said, "A somewhat similar condition might be caused by true erosion, or scour, as it is generally called. This is always found at the mud line and always between tides, but also always in very exposed positions,—on beaches where coarse gravel or sand is plentiful to act as the abrasive."[21] The fact that the tops of the stakes are associated with Shell Layer 2 is reason for suggesting the distinct possibility that the stakes were scoured off along this mud flat.[22]

It is impossible to settle the question whether or not there was sufficient material being carried about in the water over Shell Layer 2 to scour off the stakes. In support of the idea that some erosion did take place, it can be pointed out that the surface of the Upper Wattle was smooth, i.e., no twigs projected upwards from the horizontal wattles. It is possible that the surface of the wattle was scoured off during the formation of Shell Layer 2. Such scouring would also have smoothed off, if not cut off, the tops of the stakes. Observation of a relatively large quantity of sand, small pebbles, and shells in Shell Layer 2 is borne out in the analysis by Stetson and Parker. They note, "The one exception (to the sorting of materials in the deposit) is a sample taken from around the tops of the stakes in the weir itself. Here the constant is so large that the material can scarcely be said to be sorted at all."[23] This data would indicate that the material permitting a scouring of the stakes was present. Thus, an hypothesis may be proposed, namely, that the level at which the tops of the stakes were found is the result of a scouring action which occurred during the formation of Shell Layer 2. That such factors as ice or storms may have aided in the destruction seems obvious, but these were probably secondary.

In view of this hypothesis, it may be asked why no scouring took place on Shell Layer 1. The only answer is that Shell Layer 1 was not as fully developed as Shell Layer 2; and, furthermore, the necessary sand and other debris was not present. Thus, the stakes were not abraded at that level.

It is interesting to note that no debris was left after the stakes were cut off. In no place, including the Upper Wattle, were there any significant number of pieces which could have been cut off the stakes. It is difficult to avoid the assumption that the scouring action not only cut off the stakes but removed all the debris which was cut loose from them.

Interesting inferences may be made from these ideas. Shell Layer 2, being a mud line, marks the level which developed during or after the period of the abandonment of the weir. Since the lower ends of the shortest stakes

[21] William Clapp, correspondence, 10/25/40, 1/21/41.

[22] For identification of Shell Layer 2 as mud flat cf. pp. 156–157.

[23] P. 42.

were only about one foot below the surface of Shell Layer 2, it seems reasonable to believe that these stakes were driven while Shell Layer 2 was being formed. Since these were the last ones to be driven, the hypothesis that the weir was in the process of being abandoned is tenable. If such ideas are acceptable, the level of Shell Layer 2 may be used tentatively as a basis for computing subsidence since the weir was abandoned.

In figuring the amount of subsidence relative to sea level, an allowance must be made for the amount of the rise and fall of the tide. The evidence of the borers and barnacles, together with the absence of fungi, shows that the stakes must have been submerged, and so Shell Layer 2 may be considered as marking the former level of mean low water. In making this arbitrary decision, it must be borne in mind that the evidence points only to an intertidal location of the mud line. Thus, in postulating that Shell Layer 2 represents the former location of mean low water there is a possible error approximating the amount of the mean rise and fall of the tide.

PART II

THE ANALYSIS OF MATERIALS FROM THE BUILDING EXCAVATION

VARIOUS AUTHORS

CHAPTER 1

MECHANICAL ANALYSIS OF THE SEDIMENTS AND THE IDENTIFICATION OF THE FORAMINIFERA FROM THE BUILDING EXCAVATION

HENRY C. STETSON AND FRANCES L. PARKER

SEVEN samples of the sediments were taken from various locations in the building excavation. Although it was not possible to collect them from the trench, they represent a vertical section which may be considered typical of the deposit as a whole. The samples were taken from layers which had been previously identified. Mechanical analyses were made by the combined sieve and pipette method and the data plotted as cumulative curves, from which the median and the 1st and 3rd quartile diameters were read. These values were treated statistically following the method devised by Trask,[1] which facilitated the comparison of the salient characteristics of different sediments. Three constants, the median diameter, an expression for sorting and one for skewness are used. This last is chiefly of value when dealing with large numbers of samples and will be omitted here.

The median diameter, in millimeters, gives the midpoint of the size distribution of the particles of which the sample is composed. It is used for comparing variations in texture. Sorting is expressed by an index figure. It is sufficient to note here that a perfectly sorted sample (i.e., in which the grains are all of one size) would have the value of 1.00. Such conditions, of course, never occur in nature. By way of comparison, the analysis of many samples has shown that beach sands, which are among the best sorted of sediments, have an average value of about 1.25. Table II gives the percentages of certain arbitrary size limits, into which each sample has been divided, and is useful for a general survey.

At the base of the exposure is a clay formation which is usually bluish, but in the lowest parts exposed has a yellowish tinge. Three samples were taken, one about eight feet below the Lower Peat, one about six feet below, and one four feet below. The deposit is homogeneous throughout as regards texture with a median diameter ranging from .001–.003 mm. and with the

[1] Trask, P. D., 1932. *Origin and Environments of the Source Sediments of Petroleum.* Houston.

poor sorting which is characteristic of clays. The fine texture is further emphasized by the high percentages in the clay and colloid groups. The presence of foraminifera indicates that the deposit is marine. There are ten or more species of bottom living forms including: *Valvulina conica* (Parker and Jones), *Bulimina* (*Desinobulimina*) *auriculata* Bailey, *Bulimina aculeata* d'Orbigny, *Bulimina exilis* H. B. Brady, *Uvigerina peregrina* Cushman var. *bradyana* Cushman, *Elphidium incertum* (Williamson), *Cassidulina subglobosa* H. B. Brady, *Cassidulina* sp.?, *Cibicides refulgens* Montfort and *Cibicides pseudoungeriana* (Cushman). The first five of these species have not been found off this coast in water shallower than 150 meters. There are four pelagic species: *Globigerina bulloides* d'Orbigny, *Globigerina dubia* Egger, *Globigerina inflata* d'Orbigny and *Globorotalia menardii* (d'Orbigny). The presence of these together with *C. pseudoungeriana* and *U. peregrina* var. *bradyana*, which, at the present time, are only found south of Cape Cod, indicates that the water at that time was probably warmer than the present water of Massachusetts Bay.

TABLE I. MECHANICAL ANALYSES: STATISTICAL CONSTANTS

Sample	Q1 (mm.)	Median (mm.)	Q3 (mm.)	So.
1. Highest Silt, above Shell Layer 3	.113	.0445	.013	2.955
2. Silt 4′ from Peat, about −11′	.053	.0378	.0185	1.7
3. Shell Layer 2, around Top of Stakes	.0205	.0097	.0001	12.12
4. Silt just above Lower Peat	.0275	.0087	.0023	3.462
5. Clay, 4′ below Lower Peat	.016	.0031	.0005	5.45
6. Clay, 6′ below Lower Peat	.0063	.0019	.0001	7.75
7. Clay, 8′ below Lower Peat	.0126	.0032	.0009	3.78

Above the clay lies a greenish silt, which comprises the rest of the section. The samples were taken as follows: one, at the bottom; a second, from Shell Layer 2 around the tops of the stakes; a third, four feet up from the Lower Peat; and the fourth at the top, above Shell Layer 3. This silt gets progressively coarser upwards, grading from a median diameter of .008 at the bottom to .04 mm. at the top. This coarsening of texture is also reflected by higher percentages in the sand and silt grade sizes (Table II). The sorting, except in one instance, is better than that of the clay, as is usual with somewhat coarser sediments which are laid down in more agitated water. The one exception is a sample taken from Shell Layer 2, around the tops of the stakes of the weir. Here the constant is so large that the material can scarcely be said to be sorted at all. The position of the sample, however,

probably provides the explanation. The weir stakes and the "wattling" would offer an obstruction to the free flow of tidal currents, cutting down their velocity in the immediate vicinity of the weir. Consequently, the currents would drop much of their suspended load, and coarse and fine particles would be deposited together, and not selectively distributed as is the case where the flow is unimpeded. Incidentally, this should be the place of most rapid deposition. A snow fence presents a good analogy.

The foraminifera from the silt show that environmental conditions similar to those of the present day in Massachusetts Bay may have prevailed. The commonest species are *Elphidium incertum* (Williamson), *Elphidium incertum* (Williamson) var. *clavatum* Cushman and *Trochammina subturbinata* Cushman. The last species at the present time is recorded on this coast only south of latitude 39° in deep water. The rare occurrence of a few other forms suggest the possibility at least of somewhat warmer water conditions. The presence of oysters from the same formation lends additional support to this supposition.

TABLE II. MECHANICAL ANALYSES: SIZE FRACTIONS BASED ON PERCENTAGE OF TOTAL WEIGHT

Sample	Gravel 30–1 (mm.)	Sand 1–.05 (mm.)	Silt .05–.005 (mm.)	Clay .005–.001 (mm.)	Colloid .001–0 (mm.)
1. Highest Silt, above Shell Layer 3	0	46	37	8	9
2. Silt 4′ up from Peat, about −11′	0	28	54	8	10
3. Shell Layer 2	0	12	47	12	29
4. Silt just above Lower Peat	3	13	46	21	17
5. Clay, 4′ below Lower Peat	0	13	29	25	33
6. Clay, 6′ below Lower Peat	0	2	27	28	43
7. Clay, 8′ below Lower Peat	0	9	32	33	26

The environmental conditions under which the clay was deposited were very different from those prevailing today in Massachusetts Bay. As far as the writers are aware, no clay of such fine texture is being deposited in any of the estuaries of the region under present-day marine conditions. Equally fine sediments are, however, found in the deeper parts of the Gulf of Maine and on the continental slope, in some cases covered by silt. In the latter case the foraminifera likewise indicate warmer water conditions.[2] A glacial source and a subsequent reworking under marine conditions is suggested

[2] Phleger, Fred B., 1939. Foraminifera of Submarine Cores from the Continental Slope. *Bull. Geol. Soc. Amer.* Vol. 50, pp. 1395–1422.

for these clays from the estuary of the Charles River. They may possibly have been deposited just after the end of the Wisconsin period of glaciation, when the rivers flowing into the Gulf of Maine must have been transporting large quantities of the finer grade sizes. The sea of that period, therefore, would have had much fine grained material to rework, in the same way that it is transporting and distributing the present-day silt. It should be emphasized, however, that the above theory is pure assumption and is merely introduced to explain a deposit that is not forming in this region under modern marine conditions.

The silt, on the other hand, is typical of the deposits now being laid down in the harbors and tidal creeks of Massachusetts Bay. The sediment, brought into suspension by wave action during storms, is carried in by the flooding tide, and a certain amount settles out during each tide. New England streams are at present contributing practically nothing. The sedimentary data for the silt furnishes no clue as to the age of the weir, and the silt alone has been deposited since the weir was constructed. The foraminifera are all living species, and time estimates based on the supposed rates of sedimentation in near shore deposits are worthless, as they contain so many unknown factors. Deposition in a tidal estuary is particularly uncertain. What evidence we do have, however, points to the fact that during and since the period when the weir was in operation, the physical conditions in Massachusetts Bay were not greatly different from those of the present day.

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CHAPTER 2

THE MOLLUSKS

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SPECIES IDENTIFIED

ALL the following mollusks occurred at the site of the Boylston Street Fishweir. The species are listed as they were found occurring in the several strata, from the Sand Layer in the Lower Peat to the uppermost Shell Layer 3.

SAND LAYER IN LOWER PEAT

Ostrea virginica Gmelin
Modiolus demissus Dill. (fragments)
Gemma gemma Tot.

BETWEEN LOWER PEAT AND SHELL LAYER 1

Ostrea virginica Gmelin
Modiolus demissus Dill.
Macoma balthica Linn.
Crepidula plana Say
Pecten irradians Lam.
Venus mercenaria Linn.
Mulinia lateralis Say
Nassarius obsoleta Say

SHELL LAYER 1

Ostrea virginica Gmelin
Modiolus demissus Dill.
Macoma balthica Linn.
Mya arenaria Linn.
Urosalpinx cinereus Say
Pecten irradians Lam.
Venus mercenaria Linn.
Mulinia lateralis Say
Crepidula fornicata Linn.
Nassarius obsoleta Say

BETWEEN SHELL LAYERS 1 AND 2

Ostrea virginica Gmelin
Modiolus demissus Dill.
Macoma balthica Linn.
Mya arenaria Linn.
Pecten irradians Lam.
Venus mercenaria Linn.
Mulinia lateralis Say
Crepidula plana Say
Nassarius obsoleta Say

SHELL LAYER 2

Ostrea virginica Gmelin
Mytilus edulis Linn.
Venus mercenaria Linn.
Macoma balthica Linn.
Mya arenaria Linn.
Polinices heros Say
Triphoris perversa nigrocincta C. B. Adams
Urosalpinx cinereus Say

Tritia trivittata Say
Pecten irradians Lam.
Modiolus demissus Dill.
Spisula solidissima Dill.
Mulinia lateralis Say
Zirfaea crispata Linn.
Crepidula fornicata Linn.
Nassarius obsoleta Say
Tornatina canaliculata Say

Above Shell Layer 2

Ostrea virginica Gmelin
Macoma balthica Linn.
Crepidula fornicata Linn.
Mytilus edulis Linn.
Mya arenaria Linn.
Nassarius obsoleta Say

Shell Layer 3

Gemma gemma Tot.
Mulinia lateralis Say
Littorina obtusata Linn.
Macoma balthica Linn.
Mya arenaria Linn.
Nassarius obsoleta Say
Tornatina canaliculata Say

GENERAL NOTES

A few general remarks can be made on the ecology of all mollusks in this site, regardless of their stratification.

1. The species that appear on the lists above are all intertidal forms, and all, with the possible exception of *Modiolus demissus* Dill., the ribbed mussel, do exist below the low water line. The occurrence, however, of this latter species in the Sand Layer in the Lower Peat was in the form of fragments and probably drifted in with the currents. The evidence, as indicated by the above species, would show that the several deposits of mollusks were probably formed well down in the intertidal zone, at or near the low tide level.

2. All of the species encountered, other than *Littorina obtusata* Linn., are to be found on mud and sand flats. The above species, which was limited to Shell Layer 3, is found almost exclusively on the various species of rock weed. As this weed will also become attached to any submerged or fixed object such as water-logged wood, the presence of this *Littorina* is not at all abnormal. It is interesting to note that none of the common rock-loving species, which now occur abundantly on the islands in Boston Harbor, were encountered in any of the several strata at this site.

3. With the exception of *Spisula solidissima* Dill., the surf clam, and *Zirfaea crispata* Linn., the piddock, the remaining species are all known to tolerate from a little to considerable brackish water. The above two species were confined to Shell Layer 2, which is considered more in detail below. *Spisula solidissima*, however, is a species usually found under more strictly marine conditions than the present location would seem to have been. The

large group of species in this layer, many of which have somewhat different ecological requirements, would indicate that there is possibly a mixture of forms. It is possible that these several species were not necessarily living together in this location at the same time, but that they were brought together, perhaps by drifting or by some other mechanical process. The ecology of *Zirfaea crispata*, is such that it indicates some similar circumstance, though I believe it will tolerate a little more brackish water than will the *Spisula*. However, as all intertidal species are tolerant to a period of brackish water this fact only adds a little to the statements made in the above paragraph, i.e., that they may be intertidal forms and not necessarily forms continuously immersed in brackish water.

4. All of the species listed above now occur north of Cape Cod, though many, such as *Ostrea virginica* Gmel., *Pecten irradians* Lam., *Venus mercenaria* Linn., and *Triphoris perversa nigrocincta* Adams, are rare and usually limited to protected areas in harbors and coves where the water is somewhat warmer than the open sea. The *Triphoris* has only been obtained in recent times at Wellfleet, north of Cape Cod, though it is rather common south of the Cape. Only a single specimen, however, was taken at the site in Shell Layer 2, (c.f. notes on the shells of this particular stratum).

NOTES ON THE VARIOUS STRATA

(a) In the Sand Layer in the Lower Peat only three species were obtained and none were significant.

(b) Between Lower Peat and Shell Layer 1 eight species were obtained. The presence of *Ostrea*, *Pecten* and *Venus* in the list indicated that possibly the water was warmer while this deposit was accumulating than it is at present in Boston Harbor.

(c) Ten species were found in Shell Layer 1. The prevailing conditions, while this layer was being formed, were probably similar to the above (b); the additional species are similar in their ecological requirements.

(d) Between Shell Layers 1 and 2 nine species were obtained and these were similar in character to those contained in (b) and (c).

(e) In Shell Layer 2 seventeen species were collected. This is by far the most significant stratum in the entire site, not only in the number of species obtained, but in the differences in conditions that must have existed during this period of deposition. The water may have been warmer, certainly warmer than now prevails and quite probably warmer than indicated by the material contained in the four strata which lay below it. Though only a single specimen of the *Triphoris* was found, it is the only species in the entire assemblage that does not now occur north of Wellfleet, Massachu-

setts, the single locality at which this species has been collected north of Cape Cod. This is the only example of a distinctly southern element found at the site. In addition to this species are *Ostrea*, *Pecten*, and *Venus*, which are also elements indicative of a more moderate temperature condition than exists at present.

This assemblage of species would also indicate that at the time of deposition the water was probably less brackish, a condition possibly obtained by a different location of the present mouth of the Charles River. Such a change of even a short distance and with a consequent change of the tidal currents would account for a more strictly marine habitat such as now exists on the islands in the harbor and any of the several peninsulas more or less removed from the Charles, Mystic, and Neponset rivers.

(f) From above Shell Layer 2, six species, and from Shell Layer 3, seven species were collected. These appear to indicate a change in conditions. The water, as indicated by the species found, probably became colder and possibly became more brackish.

It must be considered, however, that all of the material collected in these several strata was found in a very small area. Probably many more species would have been found if the area covered had been much larger. With the possible exception of the *Triphoris*, the remaining species give an indication of changed conditions, though none other than this one species are at all conclusive in these deductions.

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CHAPTER 3

THE OYSTERS

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BECAUSE of the close connection between oysters and the stakes and wattles of the Boylston Street Fishweir a careful study of the occurrence and condition of the shells of this mollusk in the deposits should yield some interesting results. Man's extensive use of oysters for food is supplemented by the fact that this pelecypod is the marine animal best known in the scientific world.[1] Its critical temperature for spawning, 20°C., at once fixes the minimum summer temperature which must have been attained during the period in which the weir was constructed and repaired and for a considerable time thereafter. Since the oyster remains fixed for life after attachment, it is also possible to determine from the appearance of the shells whether deposition of silt was gradual or sudden. Much information can be deduced from study of the shells as to the conditions obtaining at the time the mollusks flourished. Since diatoms are the most important food of the oyster throughout the year their presence in the deposits supplies us with additional means of determining the conditions surrounding the oyster at the time of the building of the weir.

A very brief resumé of the habits of the oyster and their bearing upon the appearance and distribution of oyster shells in the deposits is required. Mass spawning of many individuals, usually in July in New England waters, liberates vast quantities of eggs and spermatozoa into the water. In twenty-four to thirty-six hours a shelled veliger develops and for the remainder of a total larval period of two weeks it swims with sufficient power to rise from the bottom to the surface while being transported by the tidal ebb and flow. By sinking during the ebb and rising on the flood oyster veligers work upstream and thus avoid being swept out to sea by the river run off.[2] Oysters

[1] Nelson, T. C., 1938. "The Feeding Mechanism of the Oyster. 1. On the Pallium and the Branchial Chambers of Ostrea virginica, O. edulis, and O. angulata, with Comparisons with Other Species of the Genus." *Jour. Morph.*, Vol. 63, pp. 1–61.

Clark, A. H., 1920. "The Smithsonian Institution, its Functions and its Future." *Science*, Vol. 63, pp. 419–441.

[2] Nelson, T. C., 1917. *Report Department of Biology, New Jersey Agricultural Experiment Station, Report for 1916*, pp. 399–430. 1921. "Aids to Successful Oyster Culture." *Bulletin* 351 *New Jersey Agricultural Experiment Station*, pp. 34–37.

require some fresh water both for setting[3] and for their subsequent growth and fattening, hence oyster beds are usually found near the mouths of rivers or in tidal estuaries.

At the close of the two weeks free-swimming period the larva attaches to some solid object to remain there for the rest of its life. Abrupt changes in the level of the bottom or obstacles in the tide way which produce eddies and slicks serve as larval "traps" in which the larvae accumulate and beneath which they usually set most heavily on the bottom if surfaces for attachment be available. Owing to the rotation of the earth the flood tide swings to the right, hence the natural oyster beds at the mouths of most rivers are usually much more extensive along the left hand bank of the river. In a large body of water such as Long Island Sound, Prytherch[4] has shown that the flood tide turns toward the Connecticut shore and that the natural oyster beds occur where this flood tide enters the brackish water areas at the mouths of streams.

Oyster larvae will attach to almost any smooth object, even marine algae such as *Fucus* and *Ulva*, or the marine "grass" *Zostera*[5] serving the purpose. Once established a group of oysters furnishes a substratum upon which subsequent broods of larvae set and grow to maturity. Starting from a single oyster successive generations branch out more and more simulating the form of a growing tree (Pl. II; VI, *a*). Clusters of oysters, originally separated, tend to approach one another, eventually becoming a continuous "reef" or natural bed of oysters. With deposition of silt and crowding of the overlying oysters the older ones are smothered and die. Their shells remain firmly bedded in the bottom, forming the supports upon which the living crust of the reef is supported (Pl. VI, *b*). One might compare a natural oyster bed or oyster reef to a gigantic molar tooth with many roots represented by the expanding columns of shells, the crown being the surface crust of living oysters.

As the bed grows upward it finally reaches a maximum upward extension close to mean low water. Where ice is heavy the surface is always below low water, whereas the oyster reefs of the southern United States, before being dredged by man, all extended well above low water.

[3] Prytherch, H. F., 1929. "Investigation of the Physical Conditions Controlling Spawning of Oysters and the Occurrence, Distribution, and Setting of Oyster Larvae in Milford Harbor." *Bulletin U. S. Bureau of Fisheries* 44, pp. 429–503. "The Role of Copper in the Setting Metamorphosis, and Distribution of the American Oyster, *Ostrea virginica*." *Ecol. Monograph*, Vol. 4, pp. 47–107.

[4] Prytherch, H. F., 1929, op. cit.

[5] Nelson, T. C., 1924. *Report Department of Biology New Jersey Agricultural Experiment Station for 1923*, pp. 317–343, New Brunswick.

Though I have only the written description of the appearance of the oyster shells in the deposit for a basis, it is evident that the excavation on Boylston Street uncovered part of an extensive oyster bed. From small beginnings on the Lower Peat, ever expanding columns of oysters rose upward as the mud and shells of Shell Layer 1 accumulated. In this layer occurs the Lower Wattle which, together with the stakes and shells of older oysters, furnished abundant surface for attachment of oyster spat. The scarcity of oysters actually attached to stakes or wattling is considered in the conclusions. By blocking the flow of the currents, larval traps were created by the weir, serving to increase the intensity of setting. Crowding of oysters by their neighbors produced the long "cat tongue" types of shells so common among the shells examined (Pl. VI, *a*, *b*, *h*). Scaling off of some of the oysters by mutual pressure, by wave action and possibly also by ice, produced groups of separate oysters under the wattle which grew into the more nearly round forms.

With increase in the numbers of oysters a general interlocking of clusters took place at the level of the Upper Wattle and of Shell Layer 2. Here was now a closely packed oyster bed, which continued to grow upward to approximately $-9'$ where it began to thin out.[6]

The heaviest concentration of shells was along the eastern side of the excavation with less along the south and east and least along the north side. This would indicate an oyster bed over which the flood tide moved northward. Oyster larvae would strike the area most heavily on the seaward and lower side with progressively less setting as the tide flowed to the north over the area. It is significant that no further driving of stakes or placing of wattle occurred subsequent to the development of a continuous bed of oysters.

Study of the oyster shells and attached materials submitted reveals the following. All but two of the oysters had been thoroughly scrubbed thus removing mud and remains of attached organisms. Fortunately these two shells still bore a thick film of fine mud and sand of quite uniform consistency. This material is similar to the mixed sand and black mud bottoms which constitute many of our best oyster producing areas today. Some of these areas are so soft as to require hardening with shells or gravel. In all cases the oysters tend to "bed in" or to sink part way into the bottom, especially during the winter. Such bottoms support excellent growths of diatoms in shallow water where sufficient light can penetrate, hence are much used by oyster growers, even though heavy losses due to burying and silting over occur during storms.[7] That the area now being considered was a

[6] P. 16. [7] Nelson, T. C., 1938. Op. cit.

favorable one for oyster production is shown not only by the abundance of shells but by the many diatoms found in the same layers.

The shells submitted were in three categories:

a. "#8. Shells with no specific location. Picked up and dug out at random for the most part in the eastern part of the excavation." In this sample were: thirteeen pairs of shells with both valves intact; thirty-eight single valves; and four fragments of valves. Of the single valves fifteen showed the inner surface of the umbo adjacent to the hinge distinctly eroded. In the others and in all the paired valves this area was uneroded. The annual rings which mark the yearly advance of the ligament stand up clearly and sharply (Pl. VI, *g*).

Sand and debris of shells recovered from washing the oysters, also without designation of the layer, revealed numerous shells of *Spisula* down to 1.5 mm. in length and 6 single valves of oysters less than two months old. These measured in length: 4.0, 4.5, 5.7, 6.7, 10.1, 10.7 mm. The last, only 4.9 mm. in height, showed effects of crowding beginning not later than two weeks after attachment. The most probable cause of crowding was a very heavy set of oysters. The shell is smooth and thin with muscle scar showing through the inner layer. This indicates rapid and vigorous growth in con-

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PLATE VI

Oysters from the building excavation.

a. Portion of an oyster "reef" showing attachment of successive generations of oysters upon older oysters forming tree-like growths upward from the bottom. The larger of the two attached oysters measures $20 \times 5\frac{1}{2}$ cm. Shell Layer 2.

b. "Mudded" oyster shells from animals buried in situ. Oyster on the right measures 15.5×5.5 cm. Shell mud stained from hinge almost to white spot near middle of shell.

c. Large shell of dead oyster attacked by Clione above the mud line. Upper limit of mud shown by pencil line. Shell 18×8 cm.

d. Large oyster of good shape attached to a vertical stake below the lower wattle. Description in text. Right valve shown in this view.

e. Same oyster as in Figure *d* from left side to show furrow formed by the stake to which the oyster was attached.

f. Young oyster showing new growth 22 mm. in extent. This oyster 69×45 mm. New growth beyond dark line.

g. Transverse ridges at the hinge end of the left valve showing the successive yearly movements of the ligament. The widest of these annual "rings" measures 4 mm., a very good growth.

h. Two oysters which were attached to stakes. The larger, 17.5×4.5 cm. shows the effects either of excessive crowding or rapid upward growth to extend above accumulating mud. The lower half of the right valve is blackened as from mud.

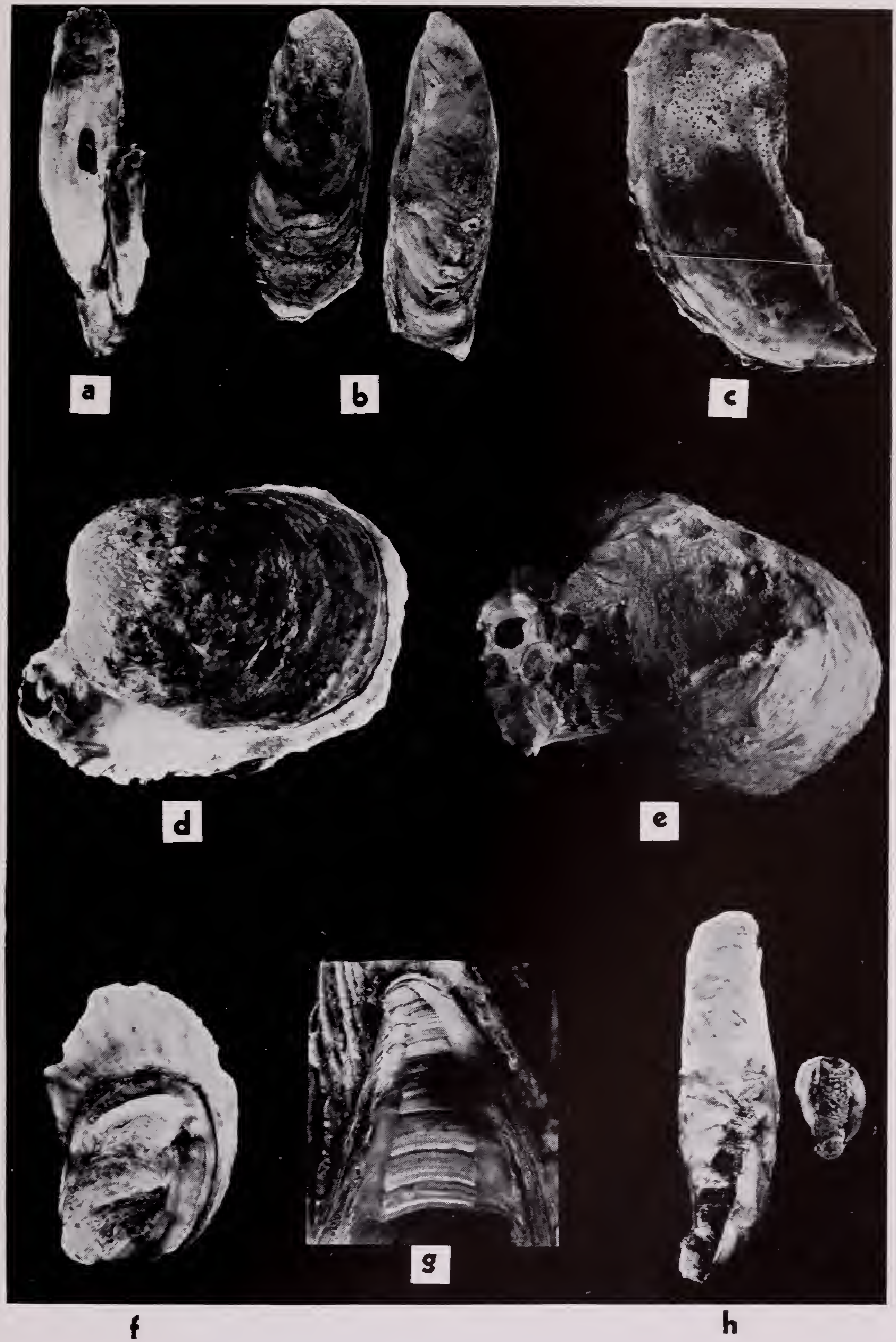

PLATE VI
(See opposite page for explanation.)

trast to the slow growth with many lines characteristic of the dumpy oyster or slowly growing oyster.[8] Since none of this material from washed oyster shells is located it is unfortunately impossible to determine at what stage in the development of the oyster bed this and the other young oysters attached. Careful searching of material surrounding the uppermost clusters of oysters might have yielded valuable information regarding the condition of the oysters at the time they were finally exterminated.

b. "#1. From just below the lower wattle. Oyster attached to barnacles on a vertical stake." This is a complete pair of shells in perfect condition, one of the most interesting in the entire collection (Pl. VI, *d*, *e*). It measures 10.1 cm. in length and 8.3 cm. in height, and would be classed in modern oyster commerce as of prime grade. An unusual feature is the very broad wing on the antero-dorsal aspect of the left valve. This wing spreads out to a distance of 3 cm. beyond the valve margin at that point half covering a large barnacle shell and completely covering eight smaller barnacles. The first year's growth stands out with exceptional clearness, 14.5×13.1 mm. This is not far from the average for the first year of growth in the Cape Cod area today. In the second year the shell followed the curvature of the stake, the straight line distance from umbo to free margin of the right valve being 44.5 mm. During its third year it extended beyond the stake reaching a total length of 68.7 mm. It died probably in the late fall of its fifth year, to judge from the appearance of the margins of the valves. The right valve still bears a heavy brown periostracum with no signs of erosion while the left valve is pearly white showing no contact with black mud. The ligament at the hinge is well preserved. The interior of the shell shows no trace of "mud pockets" caused either by encroaching mud or carried there by the mud worm *Polydora*.

The evidence is unmistakable from this pair of shells. The oyster grew rapidly, free from crowding for probably five years, attached to a stake and at such height above the bottom at all times as to be free from encroaching mud. The oyster died suddenly from deposition of rather coarse material, sand, gravel or broken shells with very little mud. It was not subsequently uncovered until excavated. The most probable cause of death was a heavy storm in the fall toward the close of the growing season. A slight fringe of new shell appears at one side but from the steepness of the margin of the left valve it is evident that this was fall, not spring, growth of shell. Considerable loose material must have been deposited at the time of death.

[8] Orton, J. H., 1926. "On Lunar Periodicity in Spawning of Normally Grown Falmouth Oysters (*O. edulis*) in 1925, with a Comparison of the Spawning Capacity of Normally Grown and Dumpy Oysters." *Journal Marine Biological Association*, Vol. 14, pp. 199–225.

c. "#4. Shells from Shell Layer 2. The shells other than those of the oysters were found inside the oyster or in the silt surrounding them." In this sample were ten pairs of shells with intact valves, eight single valves and three fragments. No washings from the shells of this layer were available. The outstanding evidence from the shells in this group is that excellent conditions for growth obtained during the period when Shell Layer 2 was being deposited and when the Upper Wattle was in place. (Pl. VI, *f*) shows an oyster probably in its third year with a fringe of new shell 21 mm. deep in its greatest extent. While not exceptional, such growth is considered very good in oysters on our best northern grounds today. The pink rays appearing in this fringe of new growth are frequently seen in rapidly growing oysters in shoal water where light easily penetrates to the bottom.

Further evidence of the rapid growth of oysters during this period is shown by the relative widths of the areas of extension of the ligament illustrated in Plate VI, *g*. Good as were the growing conditions during this period, evidence of a struggle against mud is clear. Plate VI, *b*, *right specimen*, shows the outside of a right valve of an oyster which had been buried to a depth of 6.8 cm. from the hinge for some time prior to death. The periostracum had disappeared below the mud line and three young oysters which attached to this area had been killed when about a month old. Above this line the periostracum is brilliant for 4 cm. with signs of black mud again for the last 5 cm. This oyster apparently was finally completely buried in mixed materials, coarse sand, gravel or shells in contact with the area covered by brilliant intact periostracum with black mud elsewhere. Growth was rapid and the hinge region has not been eroded. Near the posterior margin of this shell are several *Polydora* tubes which had been covered over by shell. This oyster though buried for more than one-third of its length at the anterior end and attacked by *Polydora* was winning the battle until finally completely covered. It had grown rapidly till the very end.

No shells were submitted from the very top of the bed, hence no evidence is available as to why the oysters did not continue to reproduce. It is important to know whether setting ceased at this time, indicating a change in climate with summer temperatures too low to induce spawning. Some of the shells "without location" show heavy invasion by the mudworm *Polydora*. This worm has driven the entire oyster industry of Australia off the bottom onto raised stakes and slabs of stone.[9] Recently it has caused considerable

[9] Roughley, T. C., 1922. Oyster Culture on the George's River. *Tech. Ed. Ser.* No. 25, Tech. Museum, Sydney, Australia. 1925. "The Story of the Oyster." *Australian Museum Mag.*, Vol. 2, pp. 1–32.

damage along the Atlantic seaboard of the United States.[10] Much mud was being deposited in the region of the Fishweir even during the period of most active growth of the oyster bed. Conditions were therefore ideal for extensive invasion by *Polydora*. Destruction of oysters by *Polydora* in Delaware Bay early in 1940 amounted to hundreds of thousands of dollars. The chief cause of death was not invasion between the mantle and shell with development of mud pockets, but through mud strained from the water by the worms while feeding. This mud entangled in mucus is deposited upon the oysters. When several inches have accumulated anaerobic decomposition sets in with much production of hydrogen sulphide which is quite poisonous to oysters. Observations on the shells which have been submitted suggest the possibility that *Polydora* may have contributed to the ultimate destruction of the oyster bed. A careful study of the uppermost shells would have settled this question. *Polydora* mud is very fine and sticky with but little sand. Whether the tubes of mucus and mud built by the worms would be preserved in compacted material is not known, but much could be learned from one pair of valves from the uppermost layers still enclosed in surrounding deposits.

It has been shown that oysters can continue to feed successfully and to survive in water bearing as high as .4 gm. dry weight of suspended matter per liter.[11] This material was finely divided mud with a minimum of minute sand grains. *Polydora* on certain oyster beds in Delaware Bay built up in less than six months deposits of mud from 7–6 centimeters deep. With large numbers of worms on the oyster bed and with turbid waters flowing over it *Polydora* could ultimately have buried the entire bed in question without the aid of any material washed in by storms. The appearance of shells from Shell Layer 2, indicates that *Polydora* was a minor factor in the deposition of silt.

Another enemy of the oyster, present during the period under discussion, was the boring sponge *Clione sulphurea*. This attacks the shells of both dead and living oysters. Galleries are eaten away in the shell until finally the entire shell is honeycombed. Plate VI, *c*, shows the left valve of a large oyster which for some time after the death of the oyster projected upward above the mud. The exposed portion of the shell was attacked and subse-

[10] Lunz, G. F., Jr., 1940. "The Annelid Worm, Polydora as an Oyster Pest." *Science*, Vol. 92 pp. 310.

Nelson, T. C. and L. A. Stauber, 1940. "Observations of Some Common Polychaetes on New Jersey Oyster Beds with Especial Reference to Polydora." *Anat. Rec.* 78, pp. 102–103 Suppl.

[11] Nelson, T. C., 1921. *Rept. Dept. Biology, N.J. Agr. Expt. Station for 1920*, pp. 317–349, New Brunswick.

quently riddled by *Clione*. None of the shells submitted in which both valves were attached showed the presence of *Clione*, hence it may be concluded that the oysters were vigorous, with hard shells, and that conditions were favorable. *Clione* invades most heavily where shell growth is slow and where the oysters are weakened.

According to the account of the excavation, the majority of the oyster shells were attached to the shells of other oysters lower down in the formation and not to the stakes or wattles. I have only the shells submitted as evidence. These show five shells attached to other shells, two double and twelve single shells possibly attached to other shells at some time as judged by the appearance of the hinge end, seventeen double shells and forty single shells yielding no evidence as to what, if anything, they were attached, with seven shells which clearly had been attached to stakes. The last group bears each a semi-cylindrical groove extending from the left umbo part way across the outer surface of the left valve (Pl. VI, *e*, *h*). In the twelve cases in which there can be no question whatever as to what the shells were attached, five shells are fastened to other shells while seven had been attached to stakes.

CONCLUSIONS

Fom the evidence presented by the oyster shells and from the description of the location of the stakes and their relation to the wattle, it is believed that the so-called Fishweir though perhaps used at first as a fishweir was subsequently maintained as a device to catch oysters. Linder in his most interesting chapter on the diatoms apparently entertained a similar possible conclusion: "If the weir was in some way connected with oyster culture rather than with the trapping of fish, then the questions of why complete shells were left in the beds and why there were not shell heaps in the immediate vicinity, need to be answered."[12]

It is recognized at the outset that such a revolutionary conclusion must be based upon sound evidence. It may be necessary to present a more extensive background of knowledge of the oyster and of the known instances where stakes and wattles have been employed in the catching of oysters. For the past fourteen years most of my research upon the oyster has been carried on at the New Jersey Oyster Research Laboratory at Pierces, on the Delaware Bay Shore of Cape May County. Here exist conditions which cannot differ greatly from those obtaining on the Massachusetts coast during the operation of the weir. Broad flats of mud and sand are exposed at low tide. "Lumps" of densely packed oysters occur where stakes or shells provide a

[12] P. 81.

place of attachment. Stakes are driven each year in the construction of long weirs to capture *Limulus*, the king crab. Chicken wire rather than wattle furnishes the material of the weir, but oysters set in vast abundance on the stakes. As the oysters grow some scale off through mutual pressure and develop into well-shaped oysters on the bottom along the edge of the wire. The majority, however, "fight it out" on the stakes or in dense clusters on the bottom, resulting in the long "cat tongue" oysters, so common in crowded areas and abundant in the present collection under discussion.

At the onset of cold weather in the late autumn every stake is surrounded by a mass of oysters attached to the stake and to one another. By spring, after a winter mild enough to permit the stakes to remain, scarcely an oyster can be seen. Ice and waves have knocked the oysters loose and buried them in the sand and mud of the bottom. Some of these survive and furnish a surface for attachment of the next brood of larvae.

When severe storms strike this shore, most oysters on the bottom are buried, while many more are knocked off the stakes and buried along with their brothers. Some of both groups of oysters, however, manage to survive and grow upward, while quite firmly embedded at the hinge end in the stiff mud and sand of the bottom. In severe winters heavy ice carries stakes and oysters before it. Only the densest "lumps" remain and here the oysters suffer heavy mortality through movements of the ice which breaks off the shells. It is remarkable, however, what shore oysters can stand: alternate freezing and thawing with temperatures falling well below 0°F.; grinding of ice which breaks the edges of the shells; and finally, heavy wave action with much sand and mud. If the oyster is supported above the bottom it can usually survive material in suspension up to the limit which water is capable of carrying.

In order to avoid too extensive discussion it seems best to offer the following evidence as a summary of facts.

1. "The oysters lived and increased during the period when the weir was in use."[13]

2. Oyster shells begin just above the Lower Peat, a very few shells being in contact with the peat itself. The depth to which the stakes penetrate the Lower Peat and extend into the blue clay is what would be required to hold the stakes upright, assuming that stakes began to be driven soon after the first oysters appeared.

3. The stakes were not all driven in lines as in modern fishweirs but were more or less scattered. The wattle was not woven among the stakes nor

[13] P. 18.

fastened to them. The stakes served therefore merely to keep the brush from being carried away by the tide. From the description it is hard to see how any fish as small as a herring or a shad could possibly have been captured by the contrivance. Fish schools would, however, have been deflected in their course and might ultimately have been led into a trap of close construction not unearthed by the present excavation. "In addition, single stakes were found in disturbing frequency outside these areas." ". . . there was no real evidence of weaving of brush among the stakes."..."the twigs extended haphazardly in all direction."[14] "There were also sections where either the upper or lower wattles, sometimes both were completely absent." Yet the weir was apparently extensively repaired each spring, could it have retained any fish? The wide distribution of the stakes with no "leaders" and the lack of attachment of the wattle constitute the most serious objections to considering the structure as a fishweir.

4. Whatever may have been the relationship between the stakes, wattles and the oysters, it is clearly evident that the site was occupied by an extensive oyster bed. From small beginnings this grew upward ever branching out until isolated clumps became continuous. Here and there were empty regions in some cases extending from top to bottom of the formation. Such "holes" may be found in oyster reefs today due to deposition of silt in slack areas preventing the attachment of oysters, or to current movements carrying the larvae to other areas. "There were other sections where they (oyster shells) were packed so tightly that they could not be removed until they were smashed." " . . . in a sufficient number of cases a continuous succession of shells from immediately above the peat to above Shell Layer 3 was observed." The entire description of the oyster shells found in the excavation[15] would, with but slight modification, fit any extensive natural oyster bed today, some of which show "roots" extending down into the bottom for fifty feet or more.

5. Had the weir been constructed originally and kept in repair for fish only, it would still have served as an excellent source of oysters. There is therefore nothing mutually exclusive in the two concepts as to the probable use of the structure. It is even possible that the original use was a fishweir only. On observing the excellent sets of oysters obtained the Indians may secondarily have driven extra stakes and added wattle between the original "walls" so as to secure greater sets. The data does not show that the deepest stakes had been driven in rows with the scattered stakes at a higher level. If it did, then such an interpretation would become highly plausible. One fact is certain: Unless oysters of that day were very different from modern

[14] Pp. 27, 28. [15] Pp. 16–19.

ones, a bed of oysters as extensive as this one must have been maintained by heavy sets every few years. Where wood or bark are available as well as shells these surfaces present as favorable locations for setting as do the shells. Such an extensive wooden barrier as this could not have escaped being plastered with oyster spat in each good setting year. One serious gap remains, however, in our evidence; where are the vast numbers of shells of yearling oysters that must have scaled off the stakes and bark every winter? In Cape May they are carried ashore by millions by wave action and deposited in great windrows close to high tide level.

6. The masterly analysis of the evidence from the stakes and wattles presented by Bailey and Barghoorn lends further support to the use of this structure for catching oysters. Since these mollusks were thriving, the temperature of the water must have been warmer than it is now. Herring and shad runs must, therefore, have occurred at least as early as at present, probably earlier. The evidence shows the majority of the stakes to have been cut between the middle of April and middle of June. Repairs done in the spring and early summer would have been in place in good time to catch the oyster sets, which probably began in July at the temperatures then prevailing.

7. "There is no conclusive evidence from the stakes or wattles of any pronounced climatic change during the intervening period."[16] Since the oysters thrived and multiplied during this same period we have independent evidence that the above is true. Sassafras and dogwood incidentally are now two of the dominant trees in woods adjacent to the oyster producing area of Delaware Bay, New Jersey.

8. The probable explanation of oysters below the wattling is that since it was constructed of smaller twigs, the oysters were less firmly attached thereto and tended to scale off or break away, falling to the bottom, where many of them developed into the well-shaped nearly round forms. Oysters falling from the wattling and subject to silt deposition would grow upward without in any way being attached to the wattling. The majority, however, would be carried ashore by autumn storms.

9. The abundance and types of diatoms described show them to have been most abundant during the period of greatest extension and rapid growth of the oyster bed. We also have important evidence of salinity changes which are of the utmost importance to oysters. Evidence from the diatoms indicates that when the oysters were becoming established a protective arm of land partially separated the bay from the sea, making the water warmer and lowering the salinity. This would permit oysters to

[16] P. 83.

spawn and the lowered salinity would have been favorable for development.

While the lower wattle was in place the diatoms were predominantly marine, which probably meant also colder water. Oysters, although present, grew more slowly and there were fewer of them. The species of diatoms indicate a river mouth, the area where oysters are found today. It is possible that a period of low rainfall may have occurred at this time. During the deposition of Shell Layer 2, when oysters were thriving, thirty-two species of diatoms, characteristically those of river mouths, were present.[17]

As contrasted with this, Table VIII for the top of Shell Layer 3 lists but sixteen species and there is noted ". . . a decided dropping off in the numbers of species and of specimens of diatoms." Those listed were predominantly marine. Linder suggests: "the most that can be said is that there was probably a drastic change in environmental conditions."

10. Why did the weir stop where it did? Evidence shows that at this level there was a thriving oyster bed, dense in certain areas. Such a crust of oysters and shells affords abundant surface for attachment hence stakes, even if they could have been driven through the denser portions of the bed, would have been superfluous for oyster culture. By catching seaweed, stakes and wattles accumulate much sediment. From the abundance of *Achnanthes brevipes*, Linder concludes that at least the algae *Enteromorpha* and *Cladophora* were thriving at that time. These algae use stakes for attachment and may grow in considerable profusion. It is entirely possible that much of the finer silt in which the stakes were embedded was deposited largely by reason of the interruption of current caused by stakes, wattles and their attached algae, oysters and barnacles.

11. Why did the oyster bed peter out at the surface? In the absence of shells or material accurately located in this region no answer can be given. Possible theories are: (*a*) change in climate, fall in temperature with resulting failure of oysters to spawn; (*b*) cutting a new inlet through the protecting outer beach letting in full strength sea-water with its lower temperature; (*c*) destruction of oysters by *Polydora*, as in Australia in 1888.[18] Support is given to (*b*) by the diatoms which indicate a lower temperature with more saline water in the upper part of Shell Layer 3. Similar changes in estuarine waters have occurred in Great South Bay, Long Island, and in Little Egg Harbor, New Jersey, as the result of new inlets cut through the outer beach during a hard storm. Failure of oysters to set following such changes has been clearly demonstrated in Great South Bay, Long Island, in Little Egg Harbor and Barnegat Bay, New Jersey, within recent years.

12. Further evidence of a definite change in the water is that of Clench.[19]

[17] Table VII, p. 77. [18] Roughley, 1922, 1925, op. cit. [19] P. 47–48.

From the succession of mollusks listed by him the story of the oyster through the layers can be reconstructed somewhat as follows.

Single oyster shells appear in the sand layer of the lower peat in association with fragments of *Modiolus*. This shows a location close to shore with probable exposure at low tide. Between the Lower Peat and Shell Layer 1 oysters and whole *Modiolus* become more abundant. Associated with them are their close companions of today: *Macoma*, *Crepidula*, *Pecten*, *Venus*, *Nassarius* and *Mulinia*. In Shell Layer 1 all of the preceding are represented but in addition appear *Mya* and the oyster's implacable enemy, *Urosalpinx*.

Between Shell Layers 1 and 2 *Urosalpinx* disappears to reappear in Shell Layer 2. This might be explained on our present knowledge as being due to a marked softening of the bottom. This snail thrives on the barnacle covered rocks of New England and upon dense oyster reefs. It has difficulty in navigating over soft mud.

Shell Layer 2 represents the "Golden Age," not only for the oyster, but for many other mollusks. In all, some seventeen genera are represented as against ten genera in Shell Layer 1. Two of these genera are of unusual significance, *Mytilus* and *Spisula*. Although each of these genera may appear on oyster beds, with *Mytilus* sometimes smothering out the oysters by sheer numbers, their presence there is unusual. *Mytilus edulis* and *Spisula solidissima* are essentially marine mollusks of the exposed shore lines. Both have a low critical temperature for spawning; *Mytilus* 5°C; *Spisula* probably 10°C. Both require well aerated water and thrive best where temperatures are low. The appearance of these two genera indicates a definite swing away from the warm brackish water conditions of a river mouth to the more exposed, colder, highly saline conditions of the sea. It seems, therefore, that the fate of the oyster, and with it, that of *Modiolus* and of several other mollusks, was already sealed while the upper portion of Shell Layer 2 was being deposited. Some oysters extend above Shell Layer 2 into Shell Layer 3, becoming progressively less common in the upper regions. *Urosalpinx* does not appear above Shell Layer 2, possibly barnacles and oysters were too few to prove attractive.

13. What evidence have we that stakes and wattles have ever been used to catch oysters? Here we are on firm ground, although I am not aware of any proof that American Indians ever employed such methods. The Romans, as early as the time of Marius, employed brush attached to stakes or pushed into the bottom, leaving the tops exposed at low water. With but little modification, this method of spat collecting was handed down to the Italians of modern times, who, at Lucrine Lake and at Tarente, make extensive use of brush for spat collecting. Also loose bundles of hazel or gorse

boughs, called "fascines," are suspended by ropes for collection of oyster spat.

Most extensive use is made of bamboo by the Japanese.[20] Stalks bearing their branches are fastened in veritable forests around beds of mature oysters to catch the larvae at time of attachment. In France use is now made of brush and logs for catching mussels, though formerly the same method was employed for oysters. In America scattered references are found of the use of brush for catching oysters. Extensive shucking operations, however, soon yielded an ample supply of oyster shells for this purpose.

In Australia the advent of *Polydora*, the mudworm, forced oyster growers to abandon culture on the bottom. Stone slabs, stakes and logs set on forked sticks have been employed thereafter.

14. What happened to the oyster north of Cape Cod? From the great shell mounds near Damariscotta, Maine, it is evident that, even as late as early colonial times, extensive beds of oysters existed in Maine waters. C. B. Fuller, Curator of the Portland Society of Natural History, explains the disappearance of oysters in the lower Penobscot and from Portland Harbor: " . . . by the breaking away of the barrier represented by the present chain of islands in the bay, the water of the outer sea was let fully into what had previously been a sheltered basin. This water was so very much saltier as well as colder than that to which the oysters had been accustomed that they were unable to survive the change."[21]

Verrill,[22] however, believes that a change in climate was responsible. He found under the mud at Portland great quantities of oyster shells together with those of other mollusks of warmer waters now entirely extinct in Maine, and concluded that there must have been warmer water in earlier times. He also noted these shells in the southern part of the Bay of St. Lawrence.

Unless it can be shown that these more southern species disappeared quite uniformly and over wide areas, there is little support for postulating a climatic change, especially when evidence from the diatoms and mollusk shells from the building excavation show that higher salinities accompanied the lower temperatures. Sudden burial of oysters also would accompany extensive cutting through of a headland and explain the large numbers of shells with both valves intact.

[20] Dean, B., 1893. "Report on the European Methods of Oyster Culture." *Bull. U. S. Fish Comm. for 1891*, pp. 357–406. 1903. "Japanese Oyster Culture." *Bull. U. S. Fish Comm. for 1902*, pp. 17–37.

[21] Ingersoll, E., 1881. "A Report on the Oyster Industry of the United States." *Sec. X, Tenth Census of the U. S.*, pp. 1–25, cf. p. 17.

[22] Verrill, A. E., 1872. *Invertebrates of Vineyard Sound.* Rpt. U. S. Fish Comm. for 1817.

Ingersoll refers to the natural oyster beds of the Charles and Mystic Rivers that were exhausted by the early settlers. Also the following passage from Ingersoll shows that the excavation under discussion is not the first discovery of ancient oyster beds under Boylston Street.[23]

"Through the discussion of a paper which I had the honor to read before the Boston Society of Natural History, in September, 1879, upon Massachusetts oysters, some new facts of interest were brought to light bearing upon the point now under consideration. Professor F. W. Putnam remarked that when, twenty years ago, the ground was being broken at the corner of Berkeley and Boylston Streets, for the foundation of the building devoted to this very society, in which we were then sitting, many immense oyster-shells in good condition were struck at a depth of several feet. This part of Boston is all 'made ground,' extending over former tide-flats in the 'Back bay' of Charles River. It is possible that these aged buried oysters grew on the anciently noted bed, the site of which therefore is now appropriately indicated by the Natural History Rooms and the noble Institute of Technology."

Were these "immense oyster shells in good condition" part of the formation now under discussion or something far more recent? Their location "at a depth of several feet" may indicate this, or only that the "fill" in this area was not as deep as that at the site of the present excavation. On the other hand these shells may have been a part of the very shell mounds for which Linder is asking. Were charcoal, bones of animals, and other material characteristic of the shell mounds, also found here? From the evidence at hand, the region of the Fishweir was inundated at high tide, hence would have been no place for an oyster feast. The Indians, after gathering oysters at low water, would have carried them to high ground for building a fire to open the oysters or to roast them. From the map, it seems that the excavation of some eighty years ago, referred to by Putnam, was but a few feet from the present excavation. Were the oyster shells found at the two locations part of the same formation? What other data have we on oyster shells removed from excavation in this area of Boston? Has extensive additional fill since 1859 so raised the level of Boylston Street as to account for the difference in depth of the shells in the two cases?

Finally, the second question raised by Linder is easily answered. The abundance of oyster shells with both valves intact does not mean that oysters were not being eaten. Oysters, except at low temperatures, cannot be held out of water longer than about one week. Oysters cannot be harvested at one time and stored, as are potatoes, they must be left on the beds to be

[23] Ingersoll, 1881, op. cit., p. 27, p. 20.

taken up as needed. The Indians, therefore, would have gathered only what they needed for immediate consumption, leaving the bulk of the oysters on the bed. With all the evidence before us of sudden deposition of large amounts of sediment, it is plain that great numbers of oysters were, from time to time, buried in situ and died with their valves together in the normal position.

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CHAPTER 4

NOTES ON *BALANUS EBURNEUS* GOULD

Ruth L. Lindquist and Others

PILSBRY[1] records *Balanus eburneus* Gould from Boston Harbor and from Lynn, Massachusetts. This species has never been found on the test boards of the Clapp Laboratories north of Weymouth, Massachusetts, where it occurs regularly in small numbers on the Boston Edison property at the mouth of Fore River.

Its northern limit on the Laboratory test boards on Cape Cod is Truro. It is not found on the boards from Provincetown. This species is very plentiful on the south side of Cape Cod and along the Connecticut coast. There is a heavy encrustation on the board from Saybrook at the mouth of the Connecticut River. In New York Harbor it is found occasionally on test boards in the Hudson River up as far as Weehawken and Edgewater, New Jersey.

Existing temperature records relative to the distribution of this species have not been taken regularly, nor do they cover all the months of the year. No turbidity records are at hand, but it may be estimated that *Balanus eburneus* Gould will tolerate a considerable quantity of silt. This species is found on boards upon which, in a period of eight months submersion, one eighth to one quarter of an inch of silt will settle.

* * * * *

Further information concerning *Balanus eburneus* may be supplied from various sources. Pilsbry[1] states that, "*B. eburneus* often lives in brackish water. I found small ones on the pile at Bretterton, near the head of Chesapeake Bay, where the water is but slightly brackish, the fresh-water snails *Goniobasis* and *Amnicola* living in it. Professor Wyman found it living about 50 miles up the St. Johns River, Florida, where the water was fresh enough to drink, and the specimens lived well when transferred to a vessel of perfectly fresh water."

The same author also says, "It does not often form crowded or superposed masses, as many species do, and is far oftener found on wood and oyster shells than on rocks . . . Dr. Benjamin took specimens twenty-three and one half millimeters in diameter from a Nantucket boat which had been in

[1] Pilsbry, H. A., 1916. *The Sessile Barnacles (Cirripedia) Contained in the Collections of the U. S. National Museum.* U. S. National Museum, Bulletin 93.

the water ninety-eight days, from June 13 to September 21. In a lot in the U. S. Nat. Museum, from a boat which had been in water (Quisset Harbor) some eighty days (about July 1 to September 18), the largest are twenty millimeters in diameter. Dr. F. B. Sumner has recorded specimens from twenty to twenty-six millimeters in diameter, on the bottom of a whaleboat which had been moored within the inclosure of the pier at Woods Hole from May until November or December, 1908. It appears, therefore, to attain full size in a little over three months."

Correspondence with Charles H. Blake and Henry A. Pilsbry adds that *Balanus eburneus* has been recorded from Mean Low Water to about twenty fathoms, but it does not live well above the low water mark. It often grows abundantly around and just below Mean Low Water. In fact, young *Balanus* which might become attached above low water would be promptly desiccated or frozen.

Since it is obvious that the details of the ecology of the species are not well known, only general ideas of its significance relative to the Fishweir may be offered. The species seems to exist in the southern sections of Massachusetts Bay in more or less protected places where possibly water temperatures and other conditions are favorable to its growth and reproduction. With the exception of records which have been made on boats, it seems that the colonies of this species are small, suggesting that at the present time Boston Bay is its northern limit. Larger and healthier colonies are found in Long Island Sound and to the south, where water temperatures are known to be warmer than they are in Boston Bay and where probably other conditions are more favorable. Data which may be used as an indication of the salinity of the water in the ancient Back Bay is very scanty. Pilsbry's statement that "small ones" were found along with fresh-water snails suggests the possibility that the species will survive, but not thrive, in only slightly brackish water. We can only ask if the large specimens from the Back Bay suggest that the water contained an appreciable amount of salt.

The large colony of *Balanus* on the Fishweir stakes, in which the individuals were not only more than average size, but in which they were crowded and living in superposed masses,[2] (Pl. IV, *b*, *c*) would suggest that at the time they were alive the optimum conditions obtained. It seems reasonable to assume that such optimum conditions included slightly warmer water temperatures than exist in inner Boston Harbor at the present time.

Clapp Laboratories,
Duxbury, Mass.

[2] Pp. 31–32.

CHAPTER 5

THE DIATOMS

DAVID H. LINDER

A STUDY of the diatoms found in the site of the Indian Fishweir, uncovered at some depth below the present level of the Berkeley, Clarendon, and Boylston Street area in Boston, offers some interesting problems in determining the nature of the environment at the times when the various recognizable strata were deposited. Patrick,[1] in her studies of the diatoms of the Dismal Swamp of Virginia, was able to determine definitely the level at which salt water invaded the area and also the level at which it recovered from marine influence. The Boston area, however, did not have the advantages of nearly complete protection from the sea, but, in so far as the diatomiferous layers are concerned, was always exposed to the influence of salt water. It is this fact that makes difficult any positive statement as to the nature of the habitat since, although the diatoms may roughly be classified as marine, brackish, and freshwater, there are species that are indifferent to our attempts to classify them in this manner. Kolbe,[2] recognizing this, has classified the diatoms of the Sporenberger region of Germany as *Euhalobic* (forms that are marine and are to be found in water containing 30 to 40 per cent of salt[2a]); *Mesohalobic* (forms found in brackish water containing 5 to 20 per cent of salt[2a]); and *Oligohalobic* (species which occur in freshwater or in salt concentrations of less than 5 per cent.) This last category he divides into three groups: *halophiles*, which are stimulated in their development by small concentrations of salt; *indifferent* when the species, which for the most part have been considered freshwater forms, can tolerate brackish water even though their development is retarded; and finally, *halophobic*, those forms that are strictly inhabitants of fresh water. Among those forms that he lists, and which are also found in the Boston deposits, are the following species that are arranged according to their classification in respect to the salt content of the water:

[1] Patrick, R., 1934 in Cocke, E. C., I. F. Lewis, R. Patrick, *A Further Study of Dismal Swamp Peat*, Amer. Jour. Bot. Vol. 21, pp. 374–395.

[2] Kolbe, R.W., 1927 *Zur Oekologie, Morphologie, und Systematik der Brackwasser-Diatomeen.* Pflanzenforschung, Vol. 7, pp. 1–146.

[2a] Meaning obscure, probably refers to concentration of sea water.

Euhalobic to Mesohalobic—	
	Achnanthes brevipes
Mesohalobic—	
	Achnanthes brevipes var. *intermedia*
	Cocconeis scutellum var. *parva*
	Diploneis interrupta
	Navicula digito-radiata
	N. peregrina
	Nitzschia obtusa
	Rhopalodia musculus
Oligohalobic—	
(halophile)	*Eunotia pectinalis*
(indifferent)	*Cocconeis placentula*
	Cymbella cistula
	Epithemia turgida
	Gyrosigma acuminatum vars.
	Melosira granulata
	Nitzschia angustata
	Pinnularia major (= *P. Dactylus*)
	Rhopalodia gibberula
	Surirella ovalis var. *ovata*

Among the Oligohalobic forms, it can be seen that there are a number of species that are "indifferent," or which can tolerate salty water even though growth and reproduction are retarded. According to this definition, all of the Oligohalobic-indifferent species may, for the purposes of this paper, be considered freshwater forms, since they cannot become dominant parts of a given flora unless they can reproduce themselves in the given medium. To determine which species belong in the various categories, the writer has resorted freely to the works of Cleve,[3] DeToni,[4] Hustedt,[5] and Peragallo.[6]

THE AMORPHOUS LAYER OF THE LOWER PEAT

The bottom stratum of the site, so far as the occurrence of diatoms is concerned, is the Amorphous Layer of the Lower Peat that overlays the blue clay at a depth of approximately sixteen feet below the plane of reference called Boston City Base[7] (Fig. 2). An examination of this Amorphous

[3] Cleve, P.T., 1894 *Synopsis of the Naviculoid Diatoms.* Kongl. Svenska Vetensk.-Akad. Handl. Vol. 26 (2), pp. 1–194. 1895 *Synopsis of the Naviculoid Diatoms.* Kongl. Svenska Vetensk.-Akad. Handl. Vol. 27, pp. 1–219.

[4] DeToni, J. B., 1891–1894, *Sylloge Algarum*, Vol. 2, pp 1–1557.

[5] Hustedt, F., 1927–1937, *Die Kieselalgen*, in Rabenhorst, *KryptogamenFlora vonDeutschland, Oesterreich u. der Schweiz.* Vol. 7 (1), pp. 1–920. Vol. 7 (2), pp. 1–736.

[6] Peragallo, H. & M., 1897–1908, *Diatomées Marines de France*, pp. 1–492 and I–XII.

[7] No diatoms were found in the underlying blue clay.

Layer shows that diatoms are extremely scarce. Often many fields were successively examined under the microscope without disclosing a single diatom when the fresh material was studied; yet, occasionally, a sampling slide would demonstrate that three or four specimens, predominantly *Navicula major* and *Diploneis Smithii*, were present (see Pl. VII for illustrations of Diatoms). Nor was the number of diatoms greatly increased when the sample was cleaned and concentrated. However, in addition to the two species just enumerated, there was a slight representation of the forms that are found in the stratified peat layer, called the Upper Layer, just above. The presence of diatoms in such small numbers suggests three possibilities: 1) that the few found had worked their way down from the layer above during the period of deposition of the latter, 2) that they were carried there during the excavation of the sample, or 3) that this Amorphous Layer was laid down above high water level. The first hypothesis appears to be ruled out by the structure and nature of the layer. The organic material is in a finely divided state and is closely compacted. This, plus the fact that there seems not to be a greater number of diatoms near the upper layer than close to the blue clay, would seem to indicate that the diatoms had not infiltrated from above. The second hypothesis can likewise be set aside, since the number of diatoms from the surface of the sample is not appreciably greater than from the center of the blocks of muck; and this in itself clearly shows that the diatoms were present from the start. Therefore, it would seem that the last hypothesis is the most acceptable. In view of the large numbers of diatoms found in all the upper strata, the paucity of these forms certainly is significant, and, it seems, can only be explained by postulating that the layer was laid down above sea level and was only occasionally inundated by a flood of fresh water from the Charles River as it then existed or by the backing up of brackish water at extremely high tides. Inundation by fresh water would explain the presence of *Pinnularia major* as one of the predominant forms, while brackish water would explain the presence of *Diploneis Smithii* as the other. The presence of the two together, even though in relatively small numbers, could be explained if it were possible to postulate that the area, including what is now the Back Bay, had been, at the time, a relatively elevated flat valley land traversed either by tidal brooks or by the Charles River itself; and at this point in the stream the outflowing freshwater mixed with the tidal brackish or salt water. Thus, when floods or exceptionally high tides occurred, the land was inundated, and the diatoms were left behind to become incorporated in the soil or humus layer that was then being formed. Additional evidence for the deposition of this layer above water level is furnished by the matrix, as well as by the fact that roots of a grass or

Plate VII

Diatoms from the deposits in the building excavation.

a. *Pinnularia Dactylus* Ktz., a species characteristic of freshwater and found in many of the strata of the fishweir site.

b. *Navicula granulata* Breb. of marine habitats, a not abundant species but found in most of the strata of the fishweir.

c. *Navicula peregrina* Ehr., a form of brackish waters.

d. *Pinnularia aestuarii* Cl., a species of marine to brackish waters and reported from Delaware and Connecticut. Rather abundant in the lower stratified layer of peat.

e. *Navicula formosa* var. Probably of marine habitat.

f. *Trachyneis aspera* var. *vulgaris* Cl., a marine species of wide distribution and found in the different levels of the fishweir site from below the upper wattle to below the upper peat.

g. *Actinoptychus undulatus* (Bail.) Ralfs, a marine species occurring at the mouths of rivers.

h, i. *Rhopalodia gibberula* vars., forms found in brackish and marine habitats, and in the fishweir site appearing most abundantly in the lower peat.

j. *Epithemia turgida* Ktz., a species of brackish and fresh waters. Rare in the fishweir site.

k. *Auliscus coelatus* Bail., a marine species that is also found in tidal rivers. Found in many of the upper strata of the fishweir site.

l. *Achnanthes brevipes* Ag., grows attached to algae in marine waters.

m. *Achnanthes intermedia* Ktz., a species growing attached to algae in marine and brackish waters.

n. *Rhabdonema arcuatum* (Lyngb.) Ktz., a marine species.

o. *Rhabdonema adriaticum* Ktz., a widespread marine species more commonly found in south temperate regions. It is rather abundant at the level of the lower wattle but is also found in other layers.

p. *Navicula* (Lyratae) *clavata* Greg. a marine species, very rare in the level below the lower wattle.

q. *Cocconeis scutellum* Ehrb. sensu Hustedt, a littoral species of widespread occurrence.

r. *Surirella ovata* var. *crumena* (Breb.) v.H. of brackish and fresh waters. Found at the level of the lower wattle and of the lower peat.

s. *Surirella striatula*, Turp., a species of marine and brackish waters.

t. *Diploneis Smithii* Breb. of salt and brackish waters. It is very common in the lower layer of peat, and today is more abundant south of Boston.

u. *Endictya oceanica* Ehr. is a marine species found in the upper strata of the fishweir site.

v. *Diploneis Bombus* Ehr. is found in marine habitats and in the upper layers of the fishweir site.

w. *Actinocyclus Rothii* (W. Sm.) Ralfs. A marine species found in the lower strata.

x. *Achnanthes intermedia* Ktz. (see *m.*)

y. *Coscinodiscus oculus-iridis* Ehr., a species of marine habitats and found in the lower layers.

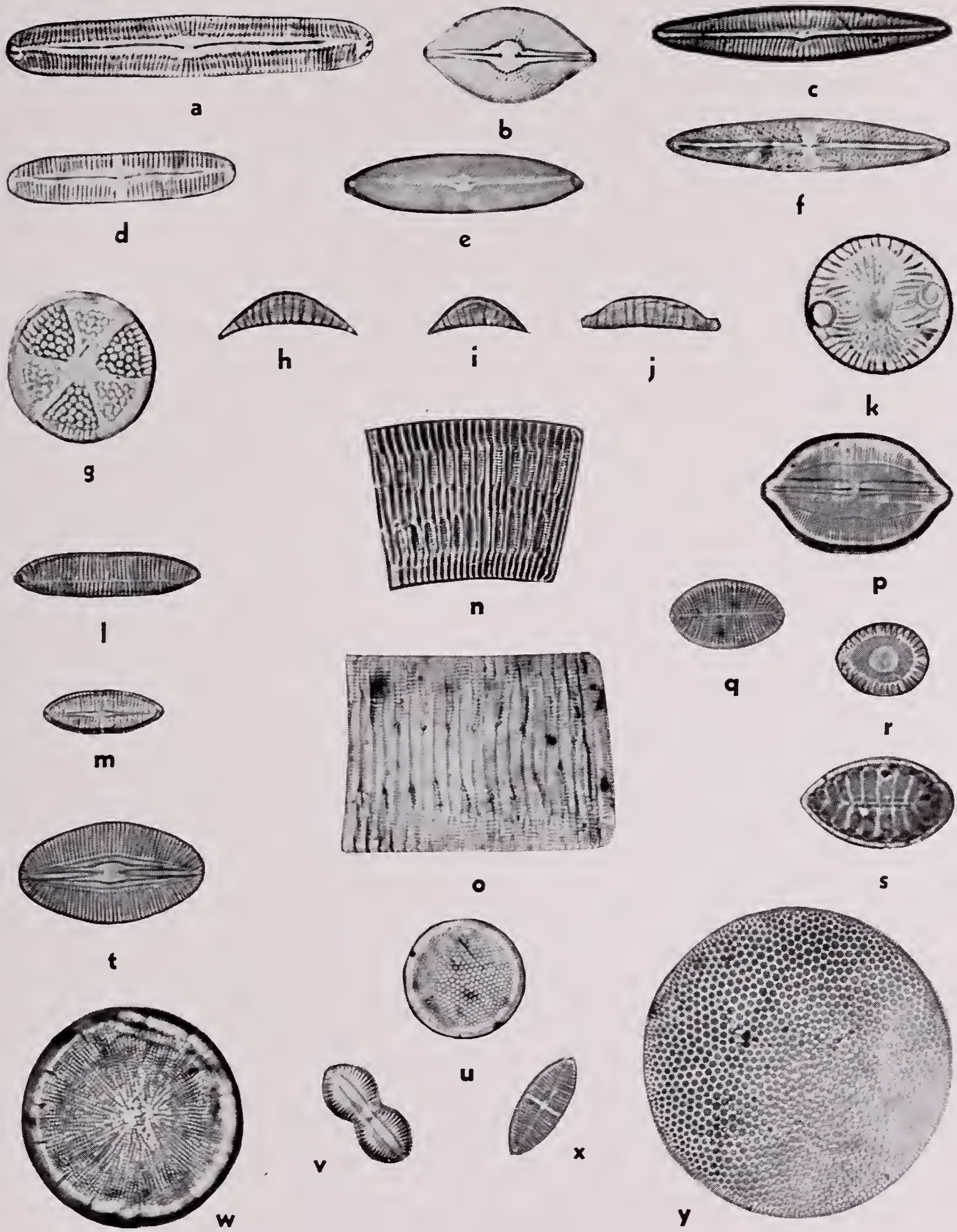

PLATE VII

(See opposite page for explanation.)

sedge were found in the blue clay below the Amorphous Layer. The matrix is extremely rich in organic material and contains some chitinous parts of insects, fragments of plant tissue that are strongly suggestive of portions of the sheaths or culms of grasses and sedges, and by fragments of fungous hyphae of which some may be recognized as belonging to dematiaceous Fungi Imperfecti, all of which indicate that this layer was laid down above water where it was possible for nearly complete decomposition of the vegetable remains to take place before the process was checked by the action of salt water.

THE UPPER LAYER OF THE LOWER PEAT

The Upper Layer overlays the Amorphous Layer and extends upward to about $-15' 8.9''$ in the eastern sections of the building excavation (Fig. 2). This layer presents quite a different picture from the one just described. The color is brownish rather than black; it is quite definitely stratified; and the plant remains have not decomposed so completely. Furthermore, the diatoms are present in very large numbers and leave very little room for doubt that during the period which saw the deposition of the layer, the area was under water. The species that have been determined are listed in Table III with an indication of the type—whether freshwater, brackish, or marine—and their relative numbers.

Of the species listed in Table III, three species are either marine or brackish water forms, six are typically marine, six typically brackish, and three are freshwater forms. Yet, despite the number of species that tolerate saline conditions, the number of individuals that are characteristically of a freshwater habitat nearly balances those, and, accordingly, it would seem that the area at the time of deposition of this layer was probably a relatively shallow, protected bay, into which the river flowed, bringing down freshwater forms that were precipitated and became mixed with the brackish and marine species. In addition to the freshwater species of diatoms that were carried downstream by the river, there is also the possibility that ponds and swamps adjacent to the shallow bay also contributed a large number of freshwater forms. Interestingly, *Achnanthes intermedia* is a species that is rather abundant in the layer, and its presence indicates that other algae also were thriving at the time, for the species is one that grows on *Enteromorpha* and *Cladophora*. Although there are some differences in the species that are present, nevertheless the Boston area of the period in which this lower layer of peat was deposited must have been somewhat similar to the conditions that exist today south of Boston in the Duxbury mud-flats. Table IV is a partial list of species found in the latter area.

Table III. Diatoms from the Upper Layer of the Lower Peat

Species	Habitat		
	marine	brackish	fresh
Achnanthes intermedia Ktz.	−	++	−
Actinocyclus Rothii (W. Sm.) Ralfs	++	−	−
Coscinodiscus oculus-iridis Ehr.	++	−	−
Diploneis Bombus Ehr.	++	−	−
Diploneis interrupta Ktz.	−	+++	−
Diploneis Smithii Breb.	++++	++++	−
Eunotia pectinalis Ktz.	−	−	+
Mastogloia elliptica (Ag.) Ktz.	+	+	−
Navicula forcipata var. *nummularia* Grev.	+	−	−
Navicula fortis Greg.	−	−	−
Navicula granulata Breb. *sensu* Peragallo	++	++	−
Navicula peregrina Ehrb.	−	++++	−
Nitzschia obtusa W. Sm.	−	(+)*	−
Nitzschia sigma var. *sigmatella* (Greg.) Grun.	−	(+)	−
Pinnularia aestuarii Cl.	+++	+++	−
Pinnularia major=*P. Dactylus* Ktz.	−	−	+++
Rhabdonema adriaticum Ktz.	+	−	−
Rhopalodia gibberula var.	++++	++++	?
Rhopalodia musculus Ktz.	−	+	−
Surirella fastuosa var.	+	−	−
Surirella ovata var. *crumena*	−	+	+

* Signs in parentheses indicate that the species is extremely rare in microscopical preparations.

Table IV. Diatoms from the Duxbury Mud Flats

Species	Habitat		
	marine	brackish	fresh
Achnanthes brevipes Ag.	+	+	−
Achnanthes intermedia Ktz.	−	+	−
Cyclotella aff. *C. compta* Ktz.	−	+++	+++
Diploneis interrupta Ktz.	−	++++	−
Diploneis Smithii Breb.	++++	++++	−
Grammatophora marina (Lyngb.) Ktz.	+	−	−
Mastogloia ovata Grun.	+	−	−
Melosira sulcata (Ehrb.) Ktz.	+++	−	−
Navicula formosa var.	+++	−	−
Navicula peregrina Ehrb.	−	++	−
Nitzschia obtusa W. Sm.	−	+	−
Rhopalodia gibberula var.	+	+	?
Surirella sp. (fragments)	(+)	−	−

From a comparison of this list with that in Table III, it will be seen that not only are there many species in common, but also that there is approximately the same proportion of marine to brackish and fresh water forms. There is, however, a rather striking difference in the numbers of *Rhopalodia gibberula* that are present in these localities, the greater numbers in the peat deposit reflecting the higher temperature of the water at that time. This same species has been seen in great numbers in material from Florida. On the other hand, *Pinnularia Dactylus* needs fresh or nearly fresh water for continued growth and reproduction. If the fresh water was not found in this locality, then at least it was only slightly higher up in the river; and from that point where the species grew rather abundantly, it may have been transported downstream in numbers to the present site in the Upper Layer. The presence of peat with evident layering, seems also to indicate that this region was protected, since it appears unlikely that there could be such a deposit of light, partially decayed, vegetable remains were the area directly exposed to the washings of the tide or the action of waves, for the intervals between tides would hardly be of sufficient duration to allow the vegetable debris to settle, become enmeshed, and compacted to withstand the erosive action.

THE SILT BELOW THE LOWER WATTLE

Above the Upper Layer and below the Lower Wattle there is a layer of silt, which, judging by the diatoms present in the stratum, is predominantly marine compared to the Upper Layer. It is characterized by a relatively large amount of fine sand and relatively small amounts of organic material. The diatoms are listed in Table V.

Of the species listed in Table V, there are only two freshwater species, *Eunotia pectinalis* and *Tryblionella lividensis*, and of these, the former was represented by but a single specimen in three large strewn slides. It, therefore, because of the paucity of specimens, seems to have been transported to this site by river currents, its presence being more or less accidental. Because of the lack of other freshwater species, it would seem that the presence of *Tryblionella lividensis* may also be explained in the same fashion. In view of the few brackish water species, the explanation seems all the more plausible, since this lack of forms from an habitat of intermediate salt concentration such as is furnished by brackish waters would rule out the normal occurrence of freshwater species in the area at this time. Indeed, the predominance of marine forms would indicate that at this period, the Fishweir site was directly exposed to marine conditions and was probably at or near the mouth of a river as is indicated by the presence of *Actinoptychus undulatus* *Synedra affinis* var. *tabulata*, *Synedra Gaillonii* var. *macilenta*, *Nitzschia*

Table V. Diatoms from the Silt Below the Lower Wattle

Species	Habitat		
	marine	brackish	fresh
Actinocyclus Ralfsii (W. Sm.) Ralfs	+	−	−
Actinoptychus undulatus (Bail.) Ralfs	+	−	−
Coscinodiscus oculus-iridis Ehr.	++	−	−
Diploneis Smithii Breb.	+	+	−
Eunotia pectinalis Ktz.	−	−	(+)
Endictya oceanica Ehr.	++	−	−
Gomphonema sp.	−	−	?
Gyrosigma balticum Sm.	+++++	−	−
Mastogloia ovata Grun.	++	−	−
Melosira sulcata (Ehr.) Ktz.	++	−	−
Navicula (*Lyratae*) *clavata* Greg.	(+)	−	−
Navicula formosa var.	++	−	−
Navicula fortis Greg.	+	−	−
Navicula granulata Breb. *sensu* Peragallo	+++	−	−
Navicula peregrina Ehrb.	−	+++	−
Navicula Zostereti Grun.	+	−	−
Nitzschia sigma var. *sigmatella* (Greg.) Grun.	+++	−	−
Rhopalodia musculus Ktz.	−	+	−
Stauroneis Gregorii Ralfs	+	−	−
Synedra affinis var. *tabulata* Grun.	+++	−	−
Synedra Gaillonii var. *macilenta* Grun.	++	−	−
Surirella Comis A. Schm.	+	−	−
Surirella intercedens Grun.	++	−	−
Trachyneis aspera var. *vulgaris* Cl.	+	−	−
Tryblionella lividensis Sm.	−	−	++

sigma var. *sigmatella*, and *Rhopalodia musculus*, which are reportedly characteristic of river mouths and of the littoral diatomaceous flora. The littoral forms which are characteristic of river mouths, in addition to the predominance of marine forms, indicate that the conditions had changed considerably during this period from those existing at the time the Upper Layer was deposited. It is obvious that the site at this period was more directly exposed to salt water; and this means that, from being a protected tidal flat influenced both by salt and fresh water, subsidence of the region brought about marine conditions which made possible the existence of the diatoms listed above. However, if the Amorphous Layer was laid down above water, and the Upper Layer was deposited in a shallow, protected, brackish body of water, then this layer, which is characteristically marine in content, above them would clearly indicate that further subsidence had taken place.

THE SILT AT THE LEVEL OF THE LOWER WATTLE (SHELL LAYER 1)

At the level of the Lower Wattle, the conditions were still predominantly marine, although again there is a return to the brackish influence, as is indicated by Table VI.

It seems probable that in this stratum, conditions were not much different from those in the preceding one. The occasional presence of the freshwater species *Pinnularia Dactylus* and *Eunotia pectinalis* may well be explained by the presence of the wattling, which provided sufficient obstruction to the flow of the river to allow the settling of those forms that had been carried down stream. That they are not present in as great numbers as in the Upper Layer may be explained by hazarding that at this time the brackish influence extended further up river, and, as a consequence, the majority of the freshwater forms had been precipitated before reaching this spot.

TABLE VI. DIATOMS FROM THE SILT AT THE LEVEL OF THE LOWER WATTLE

Species	Habitat		
	marine	brackish	fresh
Actinoptychus undulatus (Bail.) Ralfs	++++	–	–
Amphiprora alata Ktz.	(+)	(+)	–
Amphora angusta var. *typica* Cl.	+	–	–
Biddulphia aurita Breb.	+	–	–
Campylodiscus Thuretii Breb.	–	–	–
Coscinodiscus oculus-iridis Ehr.	+	–	–
Diploneis Bombus Ehr.	+	–	–
Diploneis Smithii Breb.	++	++	–
Endictya oceanica Ehr.	+	–	–
Eunotia pectinalis Ktz.	–	–	(+)
Grammatophora marina (Lyng.) Ktz.	+	–	–
Melosira Juergensii Ag.	+	+	–
Melosira nummuloides Bory	+	+	–
Navicula formosa var.	+	+	–
Navicula fortis Greg.	+	–	–
Navicula granulata Breb.	++	–	–
Nitzschia acuminata Sm.	+++	–	–
Pinnularia Dactylus Ktz.	–	–	+
Rhabdonema adriaticum Ktz.	++	–	–
Rhopalodia musculus Ktz.	–	++	–
Surirella striatula Turp.	+++	+++	–
Surirella ovata var. *crumena* (Breb.) v. H.	–	+++	+++
Trachyneis aspera var. *vulgaris* Cl.	+	–	–
Triceratium sculptum Br. var. of Peragallo	(+)	–	–

That brackish water forms appear more abundant at this level may also result from the presence of the wattle, since the obstructions would tend to check the flow of water and thus allow freshwater to mix with the salt further up river, producing as a result, conditions at the Fishweir site that were rather highly saline. As in the preceding layer, the river mouth inhabiting species are relatively abundant and this would indicate that the site was close to the mouth of the river or that the mud flats were covered by salt water at high tide, so that conditions then were nearly parallel with the conditions existing in Provincetown Harbor today. If this is so, then it would appear that salt water reached further inland during the periods in which this and the preceding layer were deposited.

LEVEL OF UPPER WATTLE AND SHELL LAYER 2

The stratum below the Upper Wattle and Shell Layer 2 contains approximately the same association of species, which indicates that the conditions were much the same when the two layers were deposited. For this reason, the species occurring in the two layers are listed in one table, Table VII.

The dominant forms in these two layers are marine, and a proportion of them characteristically inhabit the mouths of rivers. Thus, it would seem that there had been little geographic change during the period when the two layers were deposited, except perhaps for continued subsidence. The presence of *Gyrosigma balticum* in very large numbers would appear to indicate a change towards colder water; and yet, the presence of *Mastogloia ovata* and *Navicula clavata*, even though in much reduced numbers, would point to the tempering effect of shallow water heated by the sun during the period favorable for the growth and reproduction of these and similar species. Whether or not it is accepted that there was a change towards cooler waters, certainly the great numbers of diatoms at the mouth of the river would make this an ideal place for a feeding ground for fishes. In this connection, it would be interesting and significant if a correlation could be made between the "blooming" period of the diatoms and the upstream migration of fishes during the spawning season, since then it would be possible to tie this fact in with the building and repairing of the weir with sticks, which Bailey and Barghoorn[8] have found were cut in the spring.

TOP OF SHELL LAYER 3

The samples taken from the top of Shell Layer 3 show a decided dropping off in the number of species and of specimens of diatoms, although, as shown by Table VIII, the flora is dominantly marine.

[8] P. 84.

TABLE VII. DIATOMS FROM THE LEVEL OF THE UPPER WATTLE AND SHELL LAYER 2 (INCLUDES LAYERS BETWEEN SHELL LAYERS 1 AND 2)

Species	Habitat			Layer	
	marine	brackish	fresh	wattle	shell
Achnanthes brevipes Ag.	+	–	–	–	+
Actinoptychus undulatus (Bail.) Ralfs	+	–	–	+	+++
Auliscus coelatus Bail.	+	–	–	–	+
Caloneis brevis Grev.	+	–	–	+	+
Campylodiscus echineis Ehr.	+	+	–	+	+
Campylodiscus Thuretii Breb.	+	–	–	–	(+)
Cocconeis scutellum Ehr. *sensu* Hustedt	+	+	–	+++	+
Coscinodiscus oculus-iridis Ehr.	+	–	–	+	+++
Diploneis interrupta Ktz.	–	+	–	++	–
Diploneis Smithii Breb.	+	+	–	(+)	–
Endictya oceanica Ehr.	+	–	–	+++	++
Epithemia turgida Ktz.	–	+	+	+	+
Grammatophora marina (Lyngb.) Ktz.	+	–	–	+	+
Gyrosigma balticum Sm.	+	–	–	+++++	+++
Mastogloia ovata Grun.	+	–	–	++	–
Melosira granulata (Ehr.) Ralfs	–	–	+	–	(+)
Melosira sulcata (Ehr.) Ktz.	+	–	–	++	+++
Navicula (Lyratae) clavata Greg.	+	–	–	+	–
Navicula granulata Grun.	+	–	–	+	+
Navicula peregrina Ehr.	–	+	–	++	+
Nitzschia (Tryblionella) acuminata Sm.	+	–	–	++++	++++
Nitzschia (Tryblionella) punctata Sm.	–	+	+	+	+
Nitzschia sigma var. *sigmatella* (Greg.) Grun.	+	+	–	+++	+++
Pinnularia Dactylus Ktz.	–	–	+	+	+
Pleurosigma affine Grun. *sensu* Peragallo	+	–	–	–	+++
Rhabdonema adriaticum Ktz.	+	–	–	++++	++++
Rhabdonema arcuatum (Lyngb.) Ktz.	+	–	–	?	+
Surirella striatula Turp.	+	–	–	+	+
Surirella intercedens Grun. var.	+	–	–	–	(+)
Synedra affinis var. *tabulata* Grun.	+	–	–	+	?
Trachyneis aspera var. *vulgaris* Cl.	+	–	–	++	+
Triceratium reticulatum Ehr. *sensu* Hustedt	+	+	–	–	(+)

Shell Layer 3 is approximately eight feet above the Upper Wattle, and it would be interesting to speculate as to the reason for the dropping off in the quantities of diatoms. Unfortunately, there appear to be no clues, at least from the study of the diatoms, that give any indications of what has taken

TABLE VIII. DIATOMS FROM THE TOP OF SHELL LAYER 3

Species	Habitat		
	marine	brackish	fresh
Achnanthes brevipes Ag.	+	?	–
Actinoptychus undulatus (Bail.) Ralfs	+	–	–
Amphora proteus Greg.?	+	–	–
Biddulphia aurita Breb.	+	–	–
Caloneis brevis Grev.	+	–	–
Coscinodiscus oculus-iridis Ehr.	+	–	–
Cymbella cistula (Hempr.) Kirchn.	–	+	–
Diploneis Bombus Ehr.	+	–	–
Endictya oceanica Ehr.	+	–	–
Melosira crenulata (Ehr.) Ktz.	–	–	+
Melosira sulcata (Ehr.) Ktz.	+	–	–
Navicula granulata Breb.	+	–	–
Navicula digito-radiata Greg.	+	+	?
Nitzschia sigma (Ktz.) Sm.	+	–	–
Rhabdonema adriaticum Ktz.	+	–	–
Trachyneis aspera var. *vulgaris* Cl.	(+)	–	–

place. The most that can be said is that there was probably a drastic change in environmental conditions.

THE UPPER PEAT

The Upper Peat, underlying the recent fill, while containing an abundance of organic material, including fragmentary plant remains, is not so definitely stratified as is the Upper Layer, and these remains appear diluted by the greater proportion of silt. In addition to these dissimilarities, there is also a correlated difference in the number and abundance of species of diatoms, as is clearly brought out by Table IX.

Since the Upper Peat is of recent origin, it is fairly safe to conclude that the climate was probably similar to that of today. For this reason, it is interesting to make a more detailed comparison between the diatoms of this layer of peat and the Upper Layer of the Lower Peat. Among the forms in the Upper Layer we find *Diploneis Smithii* and *Pinnularia aestuarii* of the marine types; *Diploneis interrupta*, *Navicula peregrina*, and *Pinnularia aestuarii* of the brackish; and *Pinnularia Dactylus* and *Rhopalodia gibberula* of the freshwater forms. In the upper layer of peat, the marine *Gyrosigma balticum* and the brackish water inhabitant, *Navicula peregrina*, are the two most abundant forms, whereas *Diploneis Smithii* and *Pinnularia Dactylus*

are present, but in lesser numbers. At the present time, *Diploneis Smithii* and *D. interrupta* are relatively abundant on Cape Cod at Wellfleet and as far north as the Duxbury mud-flats, whereas north of Boston in the Lynn marshes, both these species are rare, and *Gyrosigma balticum* and *Pleurosigma aestuarii* Breb. are relatively abundant. The differences between the two southern stations and the northern one are quite marked in respect to the temperature of the water, but less well marked as regards climate; and from this it may be deduced that the water temperature when the Upper Layer was deposited was higher than it is today.

TABLE IX. DIATOMS FROM THE UPPER PEAT

Species	Habitat		
	marine	brackish	fresh
Actinoptychus undulatus (Bail.) Ralfs	+	–	–
Cocconeis placentula var. *lineata* (Ehr.) Cl.	–	++	–
Cymbamphora angusta Cl. var.	+	–	–
Diploneis Bombus Ehr.	+	–	–
Diploneis Smithii Breb.	++	++	–
Gyrosigma balticum (Ehr.) Sm.	+++	–	–
Melosira sulcata (Ehr.) Ktz.	+	–	–
Navicula digito-radiata Greg.	+	+	–
Navicula fortis Greg.	+	–	–
Navicula granulata Bail.	+	–	–
Navicula peregrina Ehr.	–	+++	–
Nitzschia (*Tryblionella*) *acuminata* Sm.	+	–	–
Nitzschia obtusa Sm.	–	++	–
Pinnularia Dactylus Ktz.	–	?	++

It has already been pointed out that there were differences between the upper peat deposit and the lower one. As has been suggested, the stratification of the Upper Layer, and the wealth of plant remains seems to indicate that this earlier peat deposit was laid down in a shallow, well protected bay, having a tortuous or slender connection with the harbor. Similarly, the Upper Peat must have been laid down under somewhat similar, but not identical, conditions. The abundance of organic material, as compared with that in the intermediate layers of silt would indicate that some protection was afforded by what was then a narrow isthmus connecting Boston with the mainland, namely Boston Neck. Whether or not the bay or mud flats arose from a change of the bed of the Charles River to the northward, the writer is not in a position to state, but at any rate it would seem that sufficient

protection was afforded the area so that the deposits could accumulate, yet without enough protection to allow the settling of any great amount of larger vegetable debris of low specific gravity. Thus, at the level of the Upper Peat, it would appear that while the site was protected sufficiently to allow the settling out of organic matter intermixed with silt, nevertheless it was more exposed to tidal erosion than was the Lower Peat.

SUMMARY

From this study of the diatoms and from the observation of other constituents of the various strata in the deposits of the Fishweir site, it would appear that there has been a subsidence in this area of from fourteen to eighteen feet or more. Evidence has been furnished for considering that the bottom Amorphous Layer was built up before the area had become submerged. Above this layer, the stratified Upper Layer was deposited when the locality had become submerged and had become a more or less shallow inland bay or estuary, with relatively slender connections with the harbor. Yet its connections were sufficiently ample so that it was exposed to the effects of the tide, and the water was accordingly brackish to strongly brackish although influenced by fresh water, either from seepage or from a nearby river. At this period, the water was probably considerably warmer than it is today. During the period between the accumulation of the Upper Layer and the deposition of Shell Layer 3, the land continued to sink, and, as a result, this area became more directly exposed to marine influence. Evidence for this is furnished by the presence of a preponderance of salt water forms of diatoms. The presence of *Gyrosigma balticum* seems to indicate that as soon as there was more direct exposure to the influence of the colder waters of the outer harbor, the temperature was somewhat lowered. Between the depths of $-15' \; 8.9''$ and $-14' \; 1.9''$, *Gyrosigma balticum* was present in large numbers, but between the latter level and about $-13'$, this species was quite rare and did not make its appearance in any quantity until about the $-12'$ level, after which the species persisted until recent times. In brief, while the Lower Wattle was functioning, there appears to have been an interlude when the water was warmer. This was again followed by a period during which the water became increasingly cooler. Finally, at the level of the Shell Layer 3, at $-4' \; 6''$, there was a sudden change of environmental conditions that brought about a pronounced reduction in the quantity and diversity of the diatom flora. During all this time, as is indicated by the presence of the diatoms characteristic of the river mouth, deposits were laid down in the intertidal zone, or in other words, in relatively shallow water; hence, it is safe to assume that the water cannot continue to be shallow as

deposits are made on the bottom unless there is a subsidence to compensate therefor. If further evidence of subsidence is needed, it is only necessary to note that there are two layers of wattling separated vertically by approximately two feet of silt. Indeed, those stakes of which the bases reach only to the $-13' 6''$ or the $-14' 1.9''$ level may possibly present the lower portion of even a third layer of wattling which had been destroyed through some agency, as yet unknown, just as the tops of the stakes have been cut off uniformly at about $-12' 6.4''$ in an unknown manner. However, even without the third layer of wattling, there seems to be sufficient and, to the writer, convincing evidence for the subsidence of this area. At the same time, it appears that during all the centuries intervening between the time of the deposition of the Upper Layer and the Upper Peat, the Charles River has altered its course.

As to the purpose for which the Fishweir was erected, it would seem that it was quite definitely intended to catch fish. That no *cul de sac* was found during the excavation of the site, may well be explained by the limits of the excavation, since, if the shore were gradually sloping, the stakes that have been uncovered may not have been near enough to the low tide level to warrant the construction of dead-end by-passes. At all events, the presence of diatoms in great numbers in the layers below $-4'6''$ certainly shows that an ample supply of food was present to support not only the large numbers of mollusca that were present, but also the fish that were in competition with them. If the weir was in some way connected with oyster culture, rather than with the trapping of fish, then the questions of why so many complete shells were left in the beds and of why there were not shell heaps in the immediate vicinity, need to be answered.

Contribution No. 189 from the Laboratories of Cryptogramic Botany and the Farlow Herbarium
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CHAPTER 6

IDENTIFICATION AND PHYSICAL CONDITION OF THE STAKES AND WATTLES FROM THE FISHWEIR

I. W. Bailey and Elso S. Barghoorn, Jr.

SAMPLES of one hundred and ten stakes and of thirty-four wattles were preserved in alcohol for microscopic investigation. Subsequently, these specimens were sectioned on a sliding microtome, and transverse, radial and tangential longitudinal sections were studied at various magnifications. In most cases, the specimens could be identified with certainty by the characteristic structure of their woody tissues (Pl. VIII *a–d;* Pl. IX, *a–d;* Pl. X, *a*). A few doubtful determinations were verified by a careful study of the pith (Pl. X, *c*), the type of leaf traces at the nodes, or the structure of the bark (Pl. X, *b*). For purposes of photomicrography and of permanent record, thirty-five of the specimens were embedded in paraffin prior to sectioning. The thinner sections obtained by this procedure were stained in Haidenhain's haematoxylin and safranin, dehydrated and mounted permanently in diaphane.

As indicated in Table X, material from at least seventeen genera and twenty species of trees and shrubs was utilized by the Indians in construction of the Fishweir. It seems likely, however, that the list of genera and species might be augmented if it were possible to examine a larger number of the stakes and particularly of the wattles. In the case of the stakes, it is evident that the Indians exhibited a strong preference for sassafras, beech, alder and oak, since approximately eighty per cent of the stakes were obtained from these four genera. It should be emphasized in this connection, however, that the more extensive utilization of certain species was not due in all probability to inherent physical or other properties of the plants, but rather to the fact that they were available in convenient sizes, e.g. as young, straight saplings one to four inches in diameter. The Indians obviously were not equipped with tools for rapidly felling and splitting the stems of large trees.

This selective factor must be taken into consideration in any discussion of the flora of the Boston area at the time when the Fishweir was in use. All of the genera and species listed in Table X occur in the surviving flora and may be found growing in close association at present, e.g. in the Stony

TABLE X. GENERA AND SPECIES OF TREES AND SHRUBS REPRESENTED IN THE FISHWEIR

Scientific Name	Common Name	No. of Wattles	No. of Stakes	Total No.
Dicotyledons				
Sassafras variifolium (Salisb.) Ktze.	Sassafras	5	40*	45
Quercus	Oak			
	Red-black type	4	19*	23
	White type		1	1
Alnus	Alder	4	14	18
Fagus grandifolia Ehrh.	Beech	6	4*	10
Betula	Birch			
	Gray type		4	4
	Black-yellow type	3	1	4
Cornus florida L.	Flowering Dogwood	1	6	7
Ostrya virginiana (Mill.) K. Koch.	Hop-hornbeam	2	5	7
Carya	Hickory	2	3	5
Acer	Maple			
	Soft type		4	4
	Hard type		2	2
Fraxinus americana L.	White Ash		4	4
Myrica pensylvanica Loisel.	Bayberry	3		3
Clethra alnifolia L.	Sweet Pepperbush	2		2
Platanus occidentalis L.	Sycamore		1	1
Populus	Aspen	1		1
Salix	Willow	1		1
Conifers				
Larix laricina (DuRoi) Koch.	Larch		1	1
Tsuga canadensis (L.) Carr.	Hemlock		1	1
Totals		34	110	144

* 60 additional stakes were identified as sassafras, beech or oak, but were not preserved for anatomical study.

Brook Reservation (cf. Index Map, Fig. 1). The fact that such species as chestnut and white pine are not represented in the Fishweir may be due to the fact that they were not readily available in small sizes, rather than to their absence from the local flora. Similarly, the infrequent occurrence of larch, hemlock, sycamore, poplar and white oak does not indicate necessarily actual scarcity of these trees in the primeval vegetation. Thus, the available evidence from a study of the composition of the Fishweir suggests that the flora was essentially similar to that of the Boston area at the time it was settled by the whites. *There is no conclusive evidence from the stakes or wattles of any pronounced climatic change during the intervening period.* Sassa-

fras must have been more common and available in larger sizes than at present, and the ratio of flowering dogwood is surprisingly high. However, it should be noted in this connection that sassafras was extensively cut and shipped abroad for medicinal purposes during the colonial period. Furthermore, the clearing of land for settlement, frequent fires, and the introduction of numerous pests and diseases have produced many changes in the original flora.

A detailed microscopic investigation of the stakes reveals the fact that many of them were cut shortly after the awakening of cambial activity in the spring, viz. between the middle of April and the middle of June. This may be determined by the presence of a few newly formed vessels and fibers upon the outer surface of the woody cylinder. None of them were cut during the summer or early fall, since none of them exhibit a broad zone of differentiating xylem. The stakes have either a completely differentiated outer layer of wood or incipient stages of the formation of a new annual increment of xylem. In view of the fact that the awakening of cambial activity fluctuates considerably from species to species, in individual species growing in different habitats, and in different parts of the same plant, it seems likely that all of the stakes were cut during the same season of the year. *In other words, the weir appears to have been constructed and repaired during the spring.*

The bark and wood of the stakes, except where they have been stained by contact with the peat, are comparatively light colored. The wood fluctuates from various shades of gray or brown to green, yellow or pink. In fact, it was possible to identify many of the freshly excavated stakes by their retention of colors characteristic of certain species or genera. The wood of all of the numerous dicotyledonous stakes is relatively soft and may be crushed by varying degrees of pressure between thumb and forefinger. Certain of them are mushy and very fragile, whereas others have a consistency comparable to that of a firm, compact cheese. It is not surprising, therefore, that most of the vertically placed stakes exhibit more or less numerous failures in longitudinal compression due to the weight of the overlying burden of silt and fill. Similarly, the horizontally placed wattles tend to be more or less crushed and flattened. There does not appear to be any close correlation between the present consistency of the stakes and the density of the original wood in different species. Certain of the hard-wooded hickory, beech, oak and white ash stakes have become approximately as soft as such originally less dense ones as sassafras, alder, sycamore or aspen. The dicotyledonous stakes differ markedly, however, from the two coniferous stakes (Pl. X, *a;* Pl. XI, *d*) which are harder and much stronger.

All of the dicotyledonous stakes and wattles contract greatly in drying

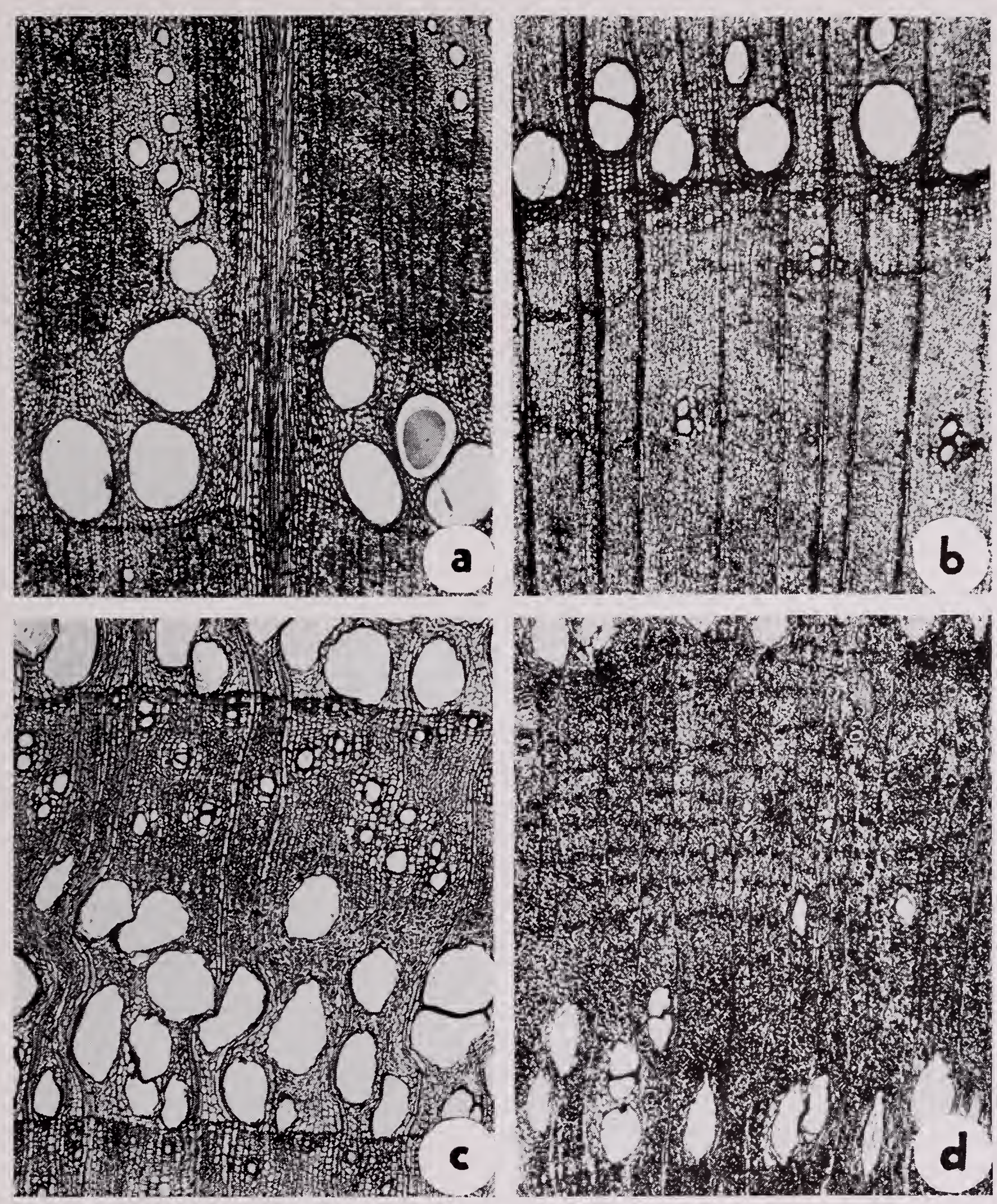

PLATE VIII

Ring-porous Dicotyledons.

a. Transverse section of the wood of stake No. 6, showing red-black oak type of structure. ×65.

b. Transverse section of the wood of stake No. 3, showing white ash type of structure. ×65.

c. Transverse section of the wood of stake No. 8, showing sassafras type of structure. ×65.

d. Transverse section of the wood of wattle No. 15, showing hickory type of structure. ×65.

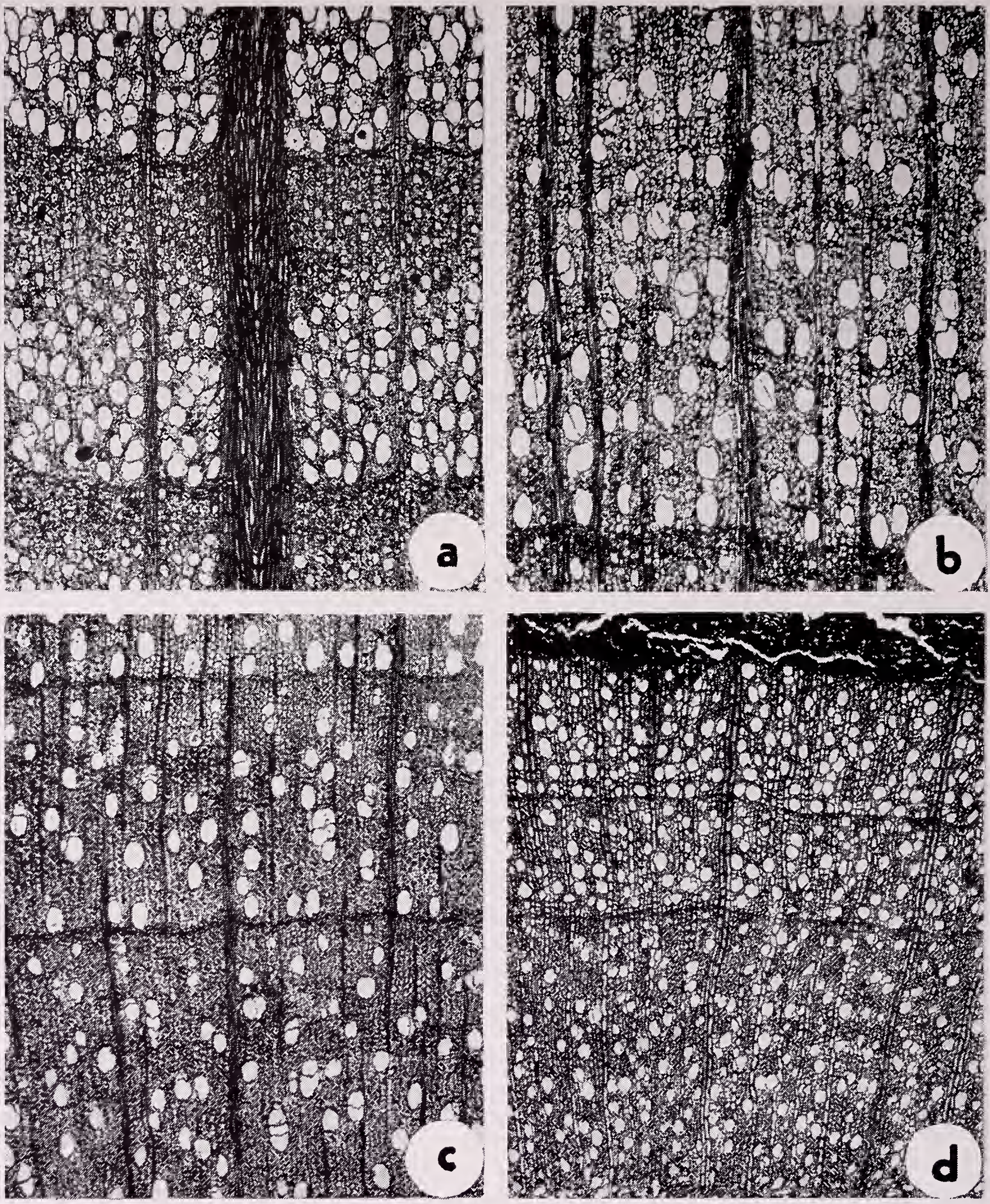

PLATE IX

Diffuse-porous Dicotyledons.

a. Transverse section of the wood of stake No. 11, showing beech type of structure. ×65.
b. Transverse section of the wood of stake No. 12, showing flowering dogwood type of structure. ×65.
c. Transverse section of the wood of stake No. 2, showing hard maple type of structure. ×65.
d. Transverse section of the wood and inner bark of wattle No. 22, showing bayberry type of structure. ×65.

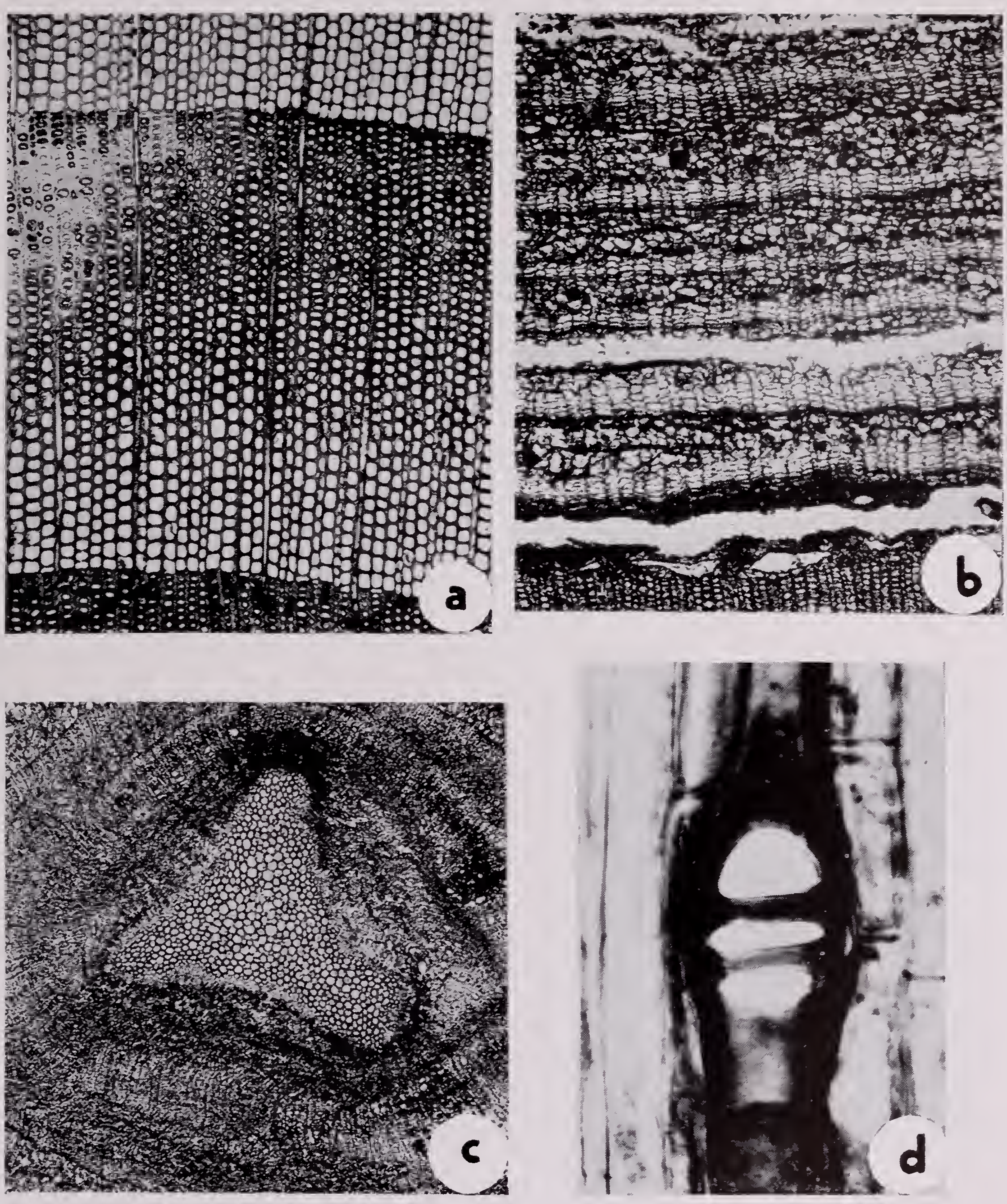

Plate X

Sections of certain characteristic stakes.

a. Transverse section of the wood of stake No. 25, showing hemlock type of structure. ×100.

b. Transverse section of the outermost wood and the bark of stake No. 1, showing sassafras type of structure. ×65.

c. Transverse section of wattle No. 18, showing the characteristic triangular pith of alder. ×50.

d. Radial longitudinal section of the wood of stake No. 1, showing late-wood vessel with scalariform perforations characteristic of sassafras. ×750.

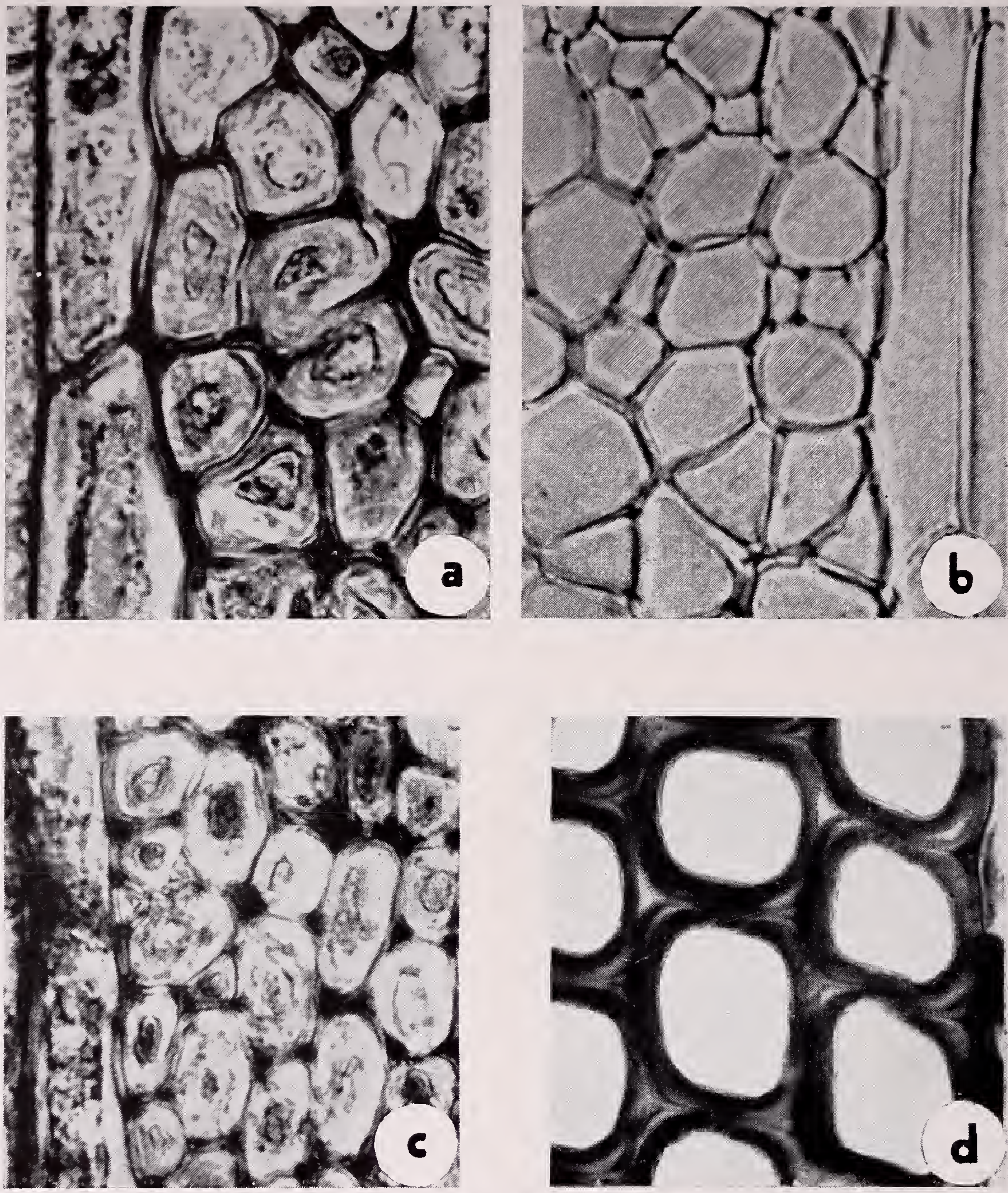

Plate XI

Three stages in the analysis of transverse sections of a hickory stake and one section, highly magnified, of stake number 25.

a. Transverse section of the wood of a hickory stake, No. 66, showing fibers and ray cells. The broad central layers of the secondary walls have disintegrated into an isotropic granular residue. ×1250.

b. Section similar to *a* delignified, showing residue of cellulose. ×1250.

c. Section similar to *a* after treatment with 72% sulphuric acid, showing lignin residue. ×1250.

d. Part of section, Plate X, *a* more highly magnified showing undecomposed secondary walls. ×1100.

and form tough, horny structures. In so doing, they crack open and warp into much modified forms. It is significant in this connection that the unmodified woods of these species contract from 4–8% radially, 7–14% tangentially, and to a negligible amount longitudinally, whereas the wood of the stakes commonly contracts from 16–24% radially, 62–75% tangentially and 15–23% longitudinally. Furthermore, the dried wood of the stakes when remoistened does not return to its original dimensions. Such facts as these, coupled with those outlined in the preceding paragraph, indicate that the physical and chemical constitution of the dicotyledonous stakes has been profoundly modified. That such is indeed the case may be determined by examining sections of the wood in ordinary light and particularly in polarized light between crossed nicols.

The secondary walls of cells in normal wood are composed of a matrix of anisotropic cellulose and thus are brilliant or birefringent in polarized light except when viewed in their positions of extinction. The wood of the coniferous stakes is strongly birefringent except on one side of the hemlock stake, which is softer, contracts more in drying and exhibits a much reduced anisotropy. In this softer tissue, certain layers of the secondary walls of the cells are isotropic or feebly birefringent, and under high magnification show various stages of disintegration into a granular residue. In the case of the so-called normal tracheids, the hydrolysis and degradation of the cellulose appear to progress more rapidly in the central layer of the secondary wall, whereas in tracheids of the so-called compression wood the broad, inner, helically laminated layer is the first to be visibly affected.

The woods of all the dicotyledonous stakes and wattles have a conspicuously modified birefringence which fluctuates from relatively feeble to barely detectable. Under higher magnifications, the secondary walls of the fibers, vessels, rays and parenchyma exhibit various stages of disintegration into an isotropic granular residue (Pl. XI, *a*). It is significant, however, that the thin outer layer of the secondary walls retains its form and some birefringence even in the softest stakes and wattles. Similarly, the primary walls and the intercellular substance or middle lamella do not disintegrate but retain their original form (Pl. XI, *a*). *A priori* one might infer from this that the persistence of these layers is due to their intense lignification. Both the isotropic and the anisotropic parts of the wood of the stakes and wattles give positive colorations with phloroglucin and hydrochloric acid and with the Mäule reaction. Furthermore, upon treatment with 72% sulphuric acid they give structural residues (Pl. XI, *c*) which are indicative of a similar distribution of lignin as in unmodified wood of the same species. This suggests that most of the lignin originally present in the stakes and wattles has per-

sisted,[1] and in the case of the middle lamella, the primary walls and the outer layer of the secondary walls has remained in situ. That the varying intensities of birefringence referred to in the preceding paragraphs are due to the persistence of varying amounts of anisotropic cellulose rather than solely to form double refraction of coherent lignin residues may be demonstrated in two ways: (1) by examining sections in liquids of varying indexes of refraction, and (2) by delignifying sections and obtaining birefringent residues (Pl. XI, *b*) which give an intense blue coloration with iodine and sulphuric acid and disappear in standard solvents of cellulose.

All of this evidence indicates that the conspicuous changes in the original physical properties of the stakes and wattles are due primarily to a gradual hydrolysis and degradation of the cellulosic matrix of the cell walls. Decreasing density, loss of strength and increasing contraction upon drying are concomitants of these chemical changes which may be roughly measured by the decreasing anisotropy of the wood. The question arises, accordingly, whether such physical and chemical changes may be utilized in estimating the interval of time that elapsed since the Fishweir was constructed. *A priori*, it seemed to us, as it will undoubtedly appear to many others, that they cannot. However, such a possibility should not be lightly dismissed without further consideration.

Plant tissues obviously decompose in different ways and at different rates depending upon their chemical composition and the particular environmental influences to which they are exposed. The decomposition of wood by fungi in warm moist air is very rapid, whereas that of coniferous timbers deeply submerged in the Miocene Gold Gravels of California is extraordinarily slow. The only possibility of estimating the time factor in the case of the Fishweir is by comparison with similar types of decomposition in comparable environments where the age of the deposits is known.

The Indians utilized three types of material in the construction of the Fishweir: (1) sound freshly cut living stems or branches, (2) injured stems or branches having partly or completely healed injuries, and (3) dead stems and branches. The stakes from sound freshly cut living stems are devoid of hyphae and of the characteristic morphological symptoms which fungi produce in attacking such tissues. The stakes cut from injured stems contain the remains of hyphae and evidences of their former enzymatic activities, but the hyphae and the symptoms of fungal activity are localized in tissues in close proximity to the injuries. The stakes from dead stems exhibit unmistakable evidence of having been attacked by fungi throughout their

[1] A conclusion that is supported by chemical analyses of the wood of the beech stakes. See pp. 92, 95.

entire length, and not infrequently by insects which feed upon dead plant tissues.

Doctor Linder, who has kindly assisted in this phase of our investigations, finds that the hyphae are dominantly of dematiaceous fungi, which are characteristically terrestrial rather than aquatic forms. This verifies our deduction that the Indians used some infected, dead and injured material, as well as freshly cut, sound, living stems and branches. *It is evident, accordingly, that the stakes and wattles must have remained submerged since they were first in the weir.* If they had been exposed to the air for a protracted period, *all* of the stakes would have become infected with bark- and wood-destroying fungi. *It is significant, in addition, that the much eroded upper ends of the stakes show no evidence of decomposition and disintegration by fungi.*

Certain of the stakes were driven through the peat into the glacial blue clay and, therefore, are embedded at present partly in those layers and partly in various depths of silt. Other stakes were subsequently driven into the accumulating silt and do not extend downward to the level of the peat. Thus, there are parts of the stakes that have been imbedded from the beginning in blue clay, peat or silt and other parts that were first submerged in water and later were covered by silt. *The condition of the bark and wood is remarkably similar throughout the length of the individual dicotyledonous stakes, regardless of the media in which they were immersed.* The hydrolysis and degradation of the cellulose appear to have progressed at an approximately similar rate in all of the various media. Furthermore, they have progressed at comparable rates in both the inner and outer parts of the stakes, in tissues having a low content of nitrogenous and pectic compounds as well as in those tissues which originally contained a high ratio of such substances. Detectable retardation of the hydrolysis and degradation of the cellulose occurs chiefly in cutinized or suberized walls, in intensely lignified walls or wall layers and in walls that contain a relatively high ratio of terpenes, resins or other so-called encrusting substances.

Such facts as these indicate that the stakes were not subjected at any time to environmental influences which favored an uneven and relatively rapid decomposition of any particular part of the stakes. On the contrary, they suggest that there was a widely diffused set of factors which produced a gradual uniform hydrolysis and degradation of the cellulose, leaving the bulk of the lignin, suberin, cutin, taninniferous substances, phlobaphenes, and other phenolic compounds more or less unmodified. Some of the phenolic substances are dark colored and are abundant in the bark of certain of the stakes. Although some of these substances—unlike the lignin—may be removed by brief treatments in dilute alkali, there is no evidence in the

stakes of an extensive formation of so-called humic compounds such as occurred in the peat.

The bulk of the peat is composed of dark, brown strata of much compressed organic material. It contains abundant fragments of various plant tissues, pollen, spores, diatoms, sponge spicules, insect chitin and other organic remains, both structural and amorphous. The fragments of leaves and stems contain numerous hyphae of terrestrial fungi, chiefly dark colored Hyphomycetes, and exhibit characteristic morphological symptoms of partial decomposition of the tissues by fungal action. These fragments fluctuate greatly in color from light brown to dark brown and to jet black. Such conspicuous variations in color occur not only within a single stratum of the peat, but also in different fragments of the same plant tissue. The brown fragments lose their color readily in dilute alkali, whereas the blackened ones do not, even after repeated treatments with chlorine and hot alkali. Both the cellulose and the lignin were modified or decomposed during the processes of humification and carbonization, but the degradation of the cellulose progressed very irregularly even in different parts of the same tissue. Pieces of dicotyledonous woods from the peat frequently show a mosaic of intensely birefringent cells scattered among others that are feebly anisotropic or isotropic.

The available evidence obtained by both Dr. Linder and ourselves indicates that most, if not all, of the fungal decomposition of the plant tissues occurred prior to their submergence, if not to their incorporation in the peat. *Furthermore, the processes of humification and of carbonization in the peat must have been inhibited or greatly retarded before the Fishweir was built.* For, if they had not, the parts of the stakes that were driven into the peat would have undergone types of decomposition similar to those that occurred in fragments of dicotyledonous woods which formed a part of the peat.

During the last thirty years one of us has examined a large number of woods that have been subjected to prolonged submergence or to burial at varying depths under sand, gravel, clay, mud, or peat. These woods were not lignites or mineralized fossils and varied in age from relatively recent to glacial or interglacial and even to Miocene. Many of them exhibit physical, chemical, and morphological changes of the type that occurred in the stakes and wattles of the Fishweir. In other words, there appears to have been a comparatively uniform and gradual hydrolysis and degradation of the cellulose leaving the lignin and not infrequently certain of the characteristically colored phenolic compounds more or less unmodified. That such changes occur more slowly in coniferous woods than in most dicotyledonous ones is evidenced, (1) by comparing the condition of the two types of wood in the

more recent deposits and (2) by the rarity or absence of dicotyledonous woods in the older geological horizons. Therefore, in searching for evidence regarding the age of the Fishweir, it is essential to focus one's attention upon possible clues concerning the rate of decomposition of dicotyledonous woods under specific conditions of submergence or of burial.

There is a very extensive but widely scattered literature from which data may be obtained regarding the appearance and the grosser physical properties of logs or stumps and of piles, timbers, pipes, or other wooden structures that have been submerged or buried for varying lengths of time. Unfortunately, there is little information concerning the visible microscopic condition of such woods or regarding their chemical composition or the processes of decomposition that they have undergone. There is one significant fact, however, that can be gleaned from the available miscellaneous information, viz. that, when *sound* wood is *permanently* submerged in fresh, brackish or salt water or is buried at some depth in sand, gravel, clay, mud or silt, the rate of decomposition is in general relatively slow. The woods of various dicotyledonous species—even such supposedly perishable ones as poplar—are frequently reported to be fairly hard and strong after periods varying from 1000 to 2000 years or more.

Piles incased in submerged strata of different composition provide the best basis for comparison with the Fishweir stakes. A study of reports regarding the condition of submerged piling driven by the Romans and by men of the successive stone, bronze, and iron age cultures of the Swiss Lakes and of other localities indicates that the dicotyledonous woods are at least as well preserved as those of the Fishweir, and that many of them are in a much better state of preservation. Thus, in view of the fact that there is no available evidence of unusual environmental influences which might have accelerated the decomposition of the Fishweir, we are inclined to believe that it dates back 2000 years or more.

It should be emphasized in conclusion that one is seriously handicapped at present in attempting analyses of this character by a dearth of reliable comparative information regarding the microscopic condition and the chemical composition of woods that have been submerged or buried for varying lengths of time, and concerning the specific types of decomposition that have occurred within them. One is further handicapped by a lack of reliable data regarding the biological and chemical variables in the media in which the woods are immersed. In these directions lie a number of promising fields for future coordinated research.

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CHAPTER 7

CHEMISTRY OF ANCIENT BEECH STAKES FROM THE FISHWEIR

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THE material to be examined was selected by Dr. I. W. Bailey from the wood collected. It consisted of short pieces of beech stakes from one to two inches in diameter. These pieces had no bark, and appeared similar to normal waterlogged wood. They showed about twenty-five annual rings and, furthermore, they were not swollen, the ring widths being normal for sticks of that age. However, these sticks were very soft and of a peculiar "cheesy" consistency and could be readily compressed between the thumb and fingers, or cut with a spatula.

A portion of the material was set aside for microscopic examination and placed in fifty per cent ethyl alcohol until used, which was about eight months later. The rest of it was placed in distilled water in a jar, the water covered with a layer of toluene and then sealed and kept in the dark about the same length of time. This was used for chemical and X-ray analysis.

Chemical analyses of other ancient woods have been reported in the literature. For example, de Lamarliére[1] found that coniferous wood freshly removed from peat beds retained its structure, although chemical analysis showed its cellulose largely gone and that most of the material behaved chemically as lignin. Waksman and Stevens[2] reported the analysis of wood from peat bogs and of fossilized oak and concluded that decomposition under anaërobic conditions brings about the disappearance of cellulose and hemicelluloses and a marked accumulation of the lignin complexes. Similar conclusions were reached by Mitchell and Ritter,[3] who analyzed three coniferous woods from Miocene auriferous gravels and found a marked decrease in the extraneous and carbohydrate content, whereas the lignin decreased

[1] de Lamarliére, L. G., 1900. Sur le bais de coniféres de tourbiéres, *Compt. rend. acad. sci.* Tome 131, pp. 511–512.

[2] Waksman, L. A. and K. R. Stevens, 1929. Processes Involved in the Decomposition of Wood with Reference to the Chemical Composition of Fossilized Wood. *Jour. Amer. Chem. Soc.*, Vol. 51, pp. 1187–1196.

[3] Mitchell, R. L. and George J. Ritter, 1934. Composition of Three Fossil Woods Mined from the Miocene Auriferous Gravels of California. *Jour. Amer. Chem. Soc.*, Vol. 56, pp. 1603–1605.

less than any other constituent. Gortner[4] analyzed several glacial and preglacial specimens of spruce and found an apparent increase in lignin and a decrease in polysaccharides with the age of the specimen.

MICROCHEMICAL STUDIES

Transverse sections fifteen microns in thickness were cut from a number of different sticks which had been kept in fifty per cent alcohol. These sections were examined under the microscope.

Plate XII, *b* shows how this wood looks in comparison to normal beech. The latter is illustrated in Plate XII, *a*. The structure appears more or less intact, but some secondary walls exhibit concentric rings, a feature not readily visible in normal unswollen beech, while many others appear disorganized into granular masses.

When viewed between the crossed Nicols of a polarizing microscope, the cell walls for the most part failed to transmit polarized light, an indication, later substantiated, that the cellulose had been largely removed or altered. In scattered patches the outer layers of the secondary walls were birefringent.

When sections were immersed in bromine water for one minute, washed, and treated with ten per cent aqueous ammonia, the typical pink color (essentially the Mäule reaction) of normal hardwoods was faintly discernible.

A most striking difference was evident between the reaction of normal beech and that of the buried stakes toward seventy-two per cent H_2SO_4, which removes cellulose (and other polysaccharides) and leaves lignin. In normal beech, the cell walls swell prodigiously, slowly dissappear and there remain only broken strings of the central layers' network so ruptured that no connected pattern can be seen. Sections from the Fishweir stakes, showed practically no swelling when immersed in seventy-two per cent H_2SO_4. Therefore, as might be expected, a nearly perfect network resulted; and moreover, even the secondary walls showed little if any more disintegration than in the untreated material. This test was made before the sections were viewed in polarized light, and it was predicted that probably little if any cellulose was present.

Plate XII, *c* shows the effect of bromination for one minute followed by washing and treatment with ten per cent ammonia. The secondary walls are cleanly and entirely removed (except in some of the ray cells). This is further evidence that practically all of the material remaining in the secondary

[4] Gortner, W. A., 1938. Analysis of Glacial and Preglacial Woods. *Jour. Amer. Chem. Soc.*, Vol. 60, pp. 2509–2511.

walls is lignin rather than cellulose. Five more brominations failed to produce maceration in normal beech or that from the stakes, but the latter were beginning to get "tender" and difficult to handle.

X-RAY ANALYSIS.[5]

Tangential sections 0.5 mm. in thickness were cut from a water-saturated stake two inches in cross section. The sections were taken from a location in the sapwood $\frac{1}{8}$ inch before the last annual ring. These were washed with alcohol, then with ether and finally air dried. Similar sections were cut from normal beech wood and the diffraction patterns of each compared with that from purified ramie cellulose. The radiation used was $Cu-K_{\alpha}$, nickel filtered. The exposure was ten hours for woods, five hours for ramie. The sample to film distance was forty-eight mm.

Examination of Plate XII, *h* reveals that the beech from the Fishweir contains cellulosic material in a non-oriented arrangement with the fiber axis. The normal beech, *e*, shows a high concentration of fairly well oriented cellulose together with lesser amounts of non-oriented cellulose. Ramie, the standard, exhibits its very well oriented cellulose structure, Plate XII, *f*, *g*.

The above interpretation is based on the relative spreading or arching of the 002 interference as well as the relative intensity of these interferences, *g* and *h*. In the ancient beech, from the Fishweir, this interference is a weak, but sharp, continuous ring, *d*. In the normal beech high intensity arcs are super-imposed upon long weaker arcs, *e*. In ramie, short high intensity arcs alone appear, *f* and *g*.

CHEMICAL ANALYSIS

Two sticks ($6\frac{1}{2}'' \times 1\ 3/16''$ and $6\frac{1}{2}'' \times 1\ 7/16''$) which had been stored in dis-

[5] X-ray analysis by Sydney Coppick, New York State College of Forestry.

PLATE XII

Transverse sections of beech wood and x-ray diffraction patterns of ancient and normal beech wood.

a. Transverse section of beech wood from the Fishweir.
b. Transverse section of normal beech wood.
c. Transverse section of beech wood from the Fishweir after bromination.
d. X-ray diffraction pattern, ancient beech Fishweir stake.
e. X-ray diffraction pattern, normal beech wood.
f. X-ray diffraction pattern, ramie fiber.
g. Principal interferences in cellulose (ramie).
h. Cross-section of cellulose chains in unit cell; projection on plane perpendicular to fiber axis.
X-ray photographs by Sydney Coppick.

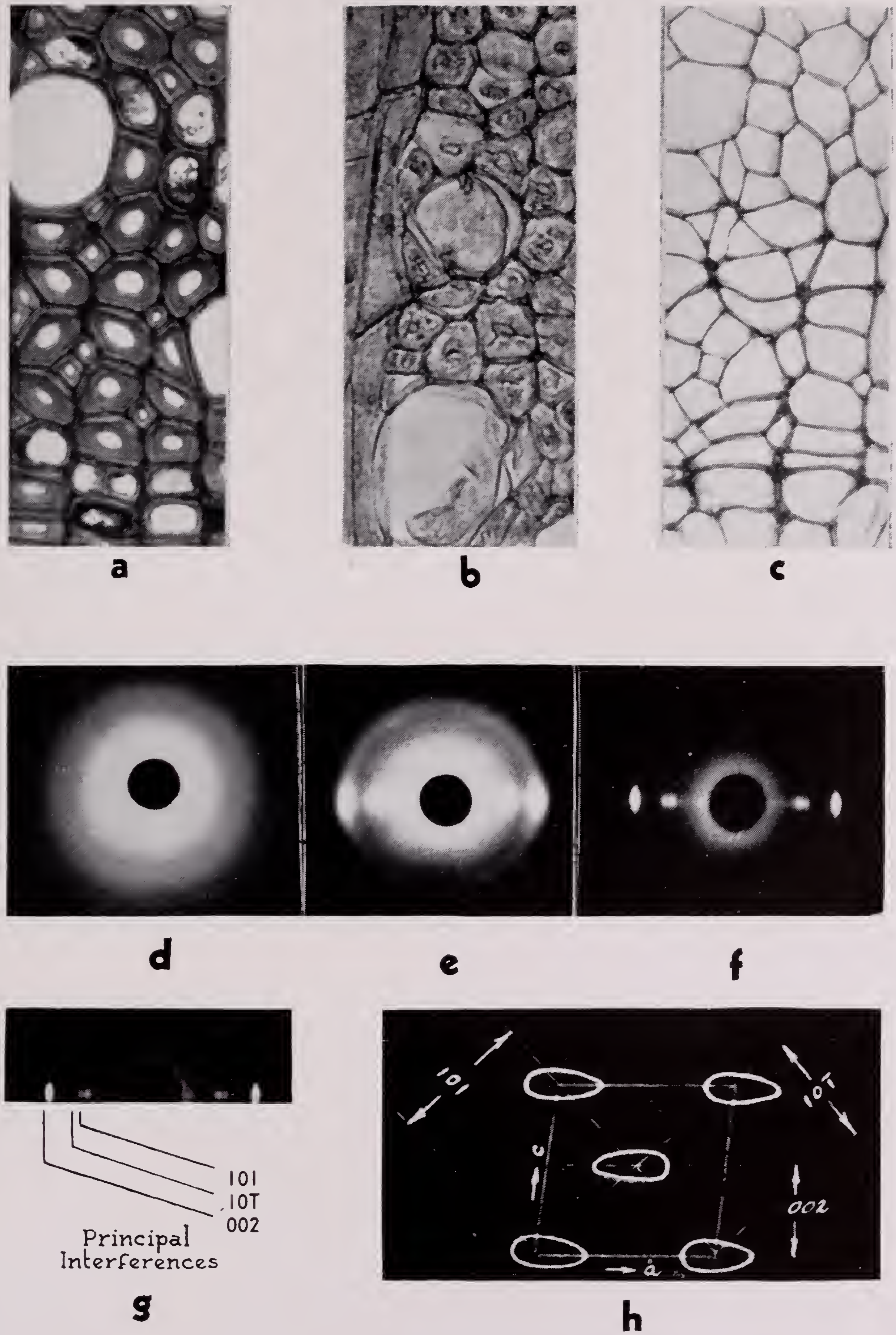

PLATE XII

(See opposite page for explanation.)

tilled water under toluene were selected for chemical analysis. The sticks were clean and sound (no rot), and, after weighing, were broken up with a spatula and air dried at 40°C. The sticks had twenty-five and twenty-six annual rings, respectively. The moisture content of the original sticks was eighty-five per cent. The dried material was ground by hand in a mortar until it passed a sixty mesh screen. The ground wood was then bottled in an air-tight bottle, and the moisture content determined as 4.68 per cent.

TABLE XI. ANALYSIS OF ANCIENT AND NORMAL BEECH WOOD

Analysis*	Ancient Beech (Basis oven dry material)	Ancient Beech (Calculated on Basis original density of wood)	Normal Beech (Basis oven dry wood)		
			Sap-wood‡	Heart-wood‡	Total Wood
Density (sp. gr.)	0.150 0.168	0.56¶			0.56¶
Copper number†	10.5				2.4
Hydrolysis number†	18.2				12.9
Ash (%)	3.45	0.99	0.31	0.57	
Alcohol-Benzene Sol'n (%)	6.56	1.88	1.37	0.96	
Pentosans (%)	7.96	2.28	25.55	24.49	
Lignin, ash free (%)	74.68	21.36	20.61	22.26	
Cellulose, lignin free (%)	11.54	3.30	60.83	60.71	

* Methoxyl analysis by Robert Anderson, after completion of this work. gave 12.20% methoxyl in ancient beech and 6.08% in normal beech.

† Determined by Sydney Coppick.

‡ Freeman, R. D. 1938. *op. cit.*

¶ Brown, H. P. and A. J. Panshin. 1934. *Identification of the Commercial Timbers of the United States.* New York.

The density of the material was measured on small pieces cut from two other sticks. The volume of each piece was determined by measuring its displacement of water in a graduated cylinder. The oven dry weight of each sample was then found, and this value divided by the original wet volume gave the density; that is, the grams of dry wood substance per cubic centimeter of space occupied by the wet tissue. This density value may be directly compared with the density of normal wood, which is the weight in grams of dry wood substance per cubic centimeter of the green tissue, Table XI.

Duplicate analyses were made on the air dry, ground material for ash, alcohol-benzene (2:1), extractives, pentosans and lignin according to the

procedure of the U. S. Forest Products Laboratory.[6] It was necessary to modify the cellulose analysis somewhat due to the very swollen and gelatinous nature of the residual cellulose which made filtration very difficult. Instead of completing the delignification by alternate gaseous chlorination and sodium sulfite digestions, the samples were given four and five of these treatments respectively, and then the residual lignin removed by digestion in dilute acidified sodium chlorite solution. The cellulose obtained was jelly-like, and each sample occupied from fifteen to eighteen cubic centimeters of space when wet. On drying, this shrank down to a very small volume, which was not over one cubic centimeter, and each sample weighed about 0.25 gm. The residual lignin in the cellulose samples was determined and found to be 2.94 per cent (0.37 per cent of the wood) and a trace (less than 0.1 per cent) respectively. The cellulose values were corrected for residual lignin. The per cent ash in the lignin was determined, and the values are expressed on the ash free basis. The per cent ash in the lignin was 0.17 and 0.13 per cent, respectively.

The reducing properties of the ancient wood were compared to normal wood by measuring their copper number by the method of Knecht and Thompson.[7] Also the hydrolysis number, that is, the copper number after boiling fifteen minutes with five per cent H_2SO_4, was determined according to the method of Schwalbe.[8] These results, together with other chemical analyses are given in Table XI. Included in this table for purposes of comparison, are values for normal beech sapwood and heartwood as determined by R. D. Freeman.[9]

DISCUSSION AND SUMMARY

Microscopic examination of the buried stakes shows that the wood has retained its structure more or less intact. However, the material behaved very unlike normal wood in its reaction to seventy-two per cent H_2SO_4 and other reagents, when observed under the microscope.

Microchemical studies of the ancient beech stakes, their behavior when viewed between crossed Nicols, and the X-ray analysis of the material all indicate that the cellulosic portion of the wood has suffered losses, and that

[6] Bray, M. W., 1939. *Methods Used at the Forest Products Laboratory for Chemical Analysis of Pulps and Pulpwoods.* Mimeograph R19, Forest Products Laboratory, Madison, Wis.

[7] Knecht, E. and L. Thompson, 1920. Rapid Method of Estimating the Reducing Values of Cellulosic Substances. *Jour. Soc. Dyers and Col.*, Vol. 36, p. 255.

[8] Schwalbe, C. G., 1909. Die Chemie der Hydratcellulosen. *Z. angew. Chem.*, Heft 22, 197 in Doree, Charles, *The Methods of Cellulose Chemistry.* New York.

[9] Freeman, R. D., 1938. *Proximate Analysis of the Heartwood and Sapwood of Some of Our Hardwoods.* Thesis, New York State College of Forestry, Syracuse, N. Y.

what cellulose remains is in an unoriented condition. Chemical analysis verified these observations.

Chemically, three-quarters of the dry tissue of the ancient stakes is lignin. Recalculation of the analytical figures on the basis of the original beech wood before it was buried, by accounting for the loss in tissue on the basis of its present density compared to the density of normal beech, shows that none of the original lignin was lost, see Table XI. The agreement of the observed lignin value with that based on the original density of the wood is striking. Conversely, if the average lignin value for normal beech sapwood and heartwood, i.e., 21.43 percent, is divided by the percent of woody tissue left in the ancient wood, which is 28.6 percent, a figure obtained from the density values of normal wood and the ancient wood, we should have 74.9 percent lignin in the ancient tissue. The actual value is 74.68 percent. It may be safely concluded, therefore, that practically none of the original lignin has been lost from these beech stakes during their long history, nor has there been any accumulation of "apparent" lignin by the alteration or decomposition of other constituents.

Based on the original density of the wood, there has been some increase in the ash content and the alcohol-benzene soluble extractives, whereas most of the pentosans and cellulose have been lost. About ninety-one percent of the original pentosans and about ninety-five percent of the original cellulose has been destroyed.

The very high reducing power of the ancient wood despite its low polysaccharide content indicates that this small fraction of cellulosic material is highly degraded. Probably it is an "oxycellulose" with a high proportion of carbonyl and carboxyl groups. Furthermore, it is likely that the molecular chains are greatly shortened, as may be deduced in part from the X-ray analysis.

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CHAPTER 8

THE POLLEN ANALYSIS OF THE LOWER PEAT

William S. Benninghoff

INTRODUCTION

THE author has performed an analysis of the pollen in the Lower Peat in the building excavation in an attempt to date the deposit and the Fishweir. A block of the Lower Peat, representing a complete section, was taken from a place in the northwestern section of the building excavation by Frederick Johnson and I. W. Bailey. The block was preserved in formalin solution, and samples for pollen analysis were taken at six levels within the eight and one-half inch section.

In the locality of the trench where detailed investigations were carried on, the Lower Peat averages nine inches in thickness and rests unconformably upon Blue Clay. At this same locality the peat is overlain with about fifteen feet nine inches of silt, at the top of which is the layer of the "Upper Peat." Above the silt there is about eighteen feet of recent fill. The exact horizontal extent of the Lower Peat is not known, but it is believed to be distributed over the central portion of the original Back Bay.[1] That this peat is almost entirely allochthonous is demonstrated by the abundance of insect chitin and fungal hyphae, the presence of a considerable quantity of micaceous sand, and the greatly fragmented plant remains. Many of the pollen grains, including types generally very well preserved (*Quercus*, *Tsuga*, *Pinus*, etc.), were badly damaged. The percentages of the *Pinus* pollen counts based upon wings severed from the whole grains[2] are shown in Figure 6. The graph of these percentages demonstrates the rather consistent allochthonous character of the peat.

METHOD

Six samples of approximately 5 cc. each were cut from a clean surface on the block of peat, at depths of $8\frac{1}{4}$,″ 7″, 5, ″4,″ 3,″ and $\frac{1}{4}$″ in the section.

[1] Cf., pp. 150–156 and pp. 13–22 for description of cross section and discussion of the distribution of the peat beds.

[2] The pollen grain of *Pinus* has an ovoid central portion with a bulbous "wing" at each end. In the pollen counts the number of isolated wings was divided by two in order to approximate the representation of intact *Pinus* grains.

From each sample approximately 1 cc. was taken, placed in 60% hydrofluoric acid for 6 hours, and washed with a gentle flow of tap water for 1 hour. Thus, nearly all of the micaceous sand and diatoms were removed. Because of the comparatively low pollen frequency and the high lignin content of the peat, the Barghoorn and Bailey[3] method of preparation was employed throughout. The desilicified peat was subjected to alternate treatments with strong chlorine water and hot (80°C.) 4% sodium sulphite

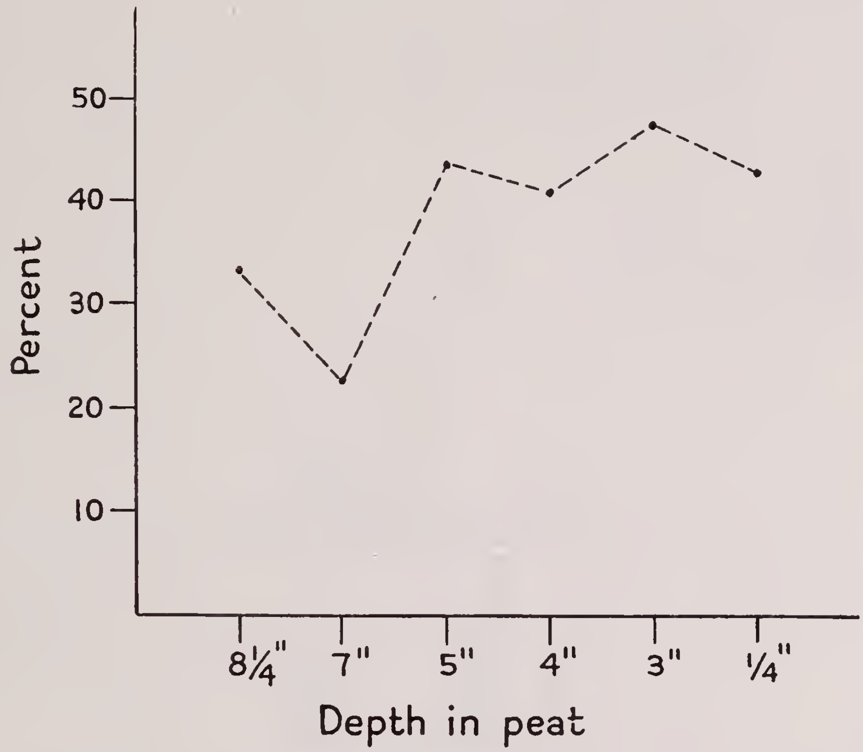

FIG. 6. Percentage of *Pinus* bladders (n/2) represented in the *Pinus* pollen counts.

solution. After each treatment the mixture was centrifuged, and the supernatant liquid was decanted. Five treatments with each solution were carried out, followed by a sixth chlorination; and, finally, the residue was washed with distilled water. By this method all of the vegetable debris, except the pollen, was bleached until translucent, an end result very similar to that achieved by Erdtman's acetolysis method.[4] Each sample of prepared peat was mixed with 3 cc. of concentrated lactic acid. Material prepared in this manner may be kept in bottles for reference as long as is desired. Approximately 1/20 cc. of this prepared material was placed on a clean slide, and covered with a 22×30 cover glass. It was found that addition of a very

[3] Barghoorn, E. and I. W. Bailey, 1940. A Useful Method for the Study of Pollen in Peat, *Ecology*, vol. 21, pp. 513–514.

[4] Erdtman, G., 1936. New Methods in Pollen Analysis. *Svensk Bot. Tidsskrift*, Vol. 30, pp. 154–164.

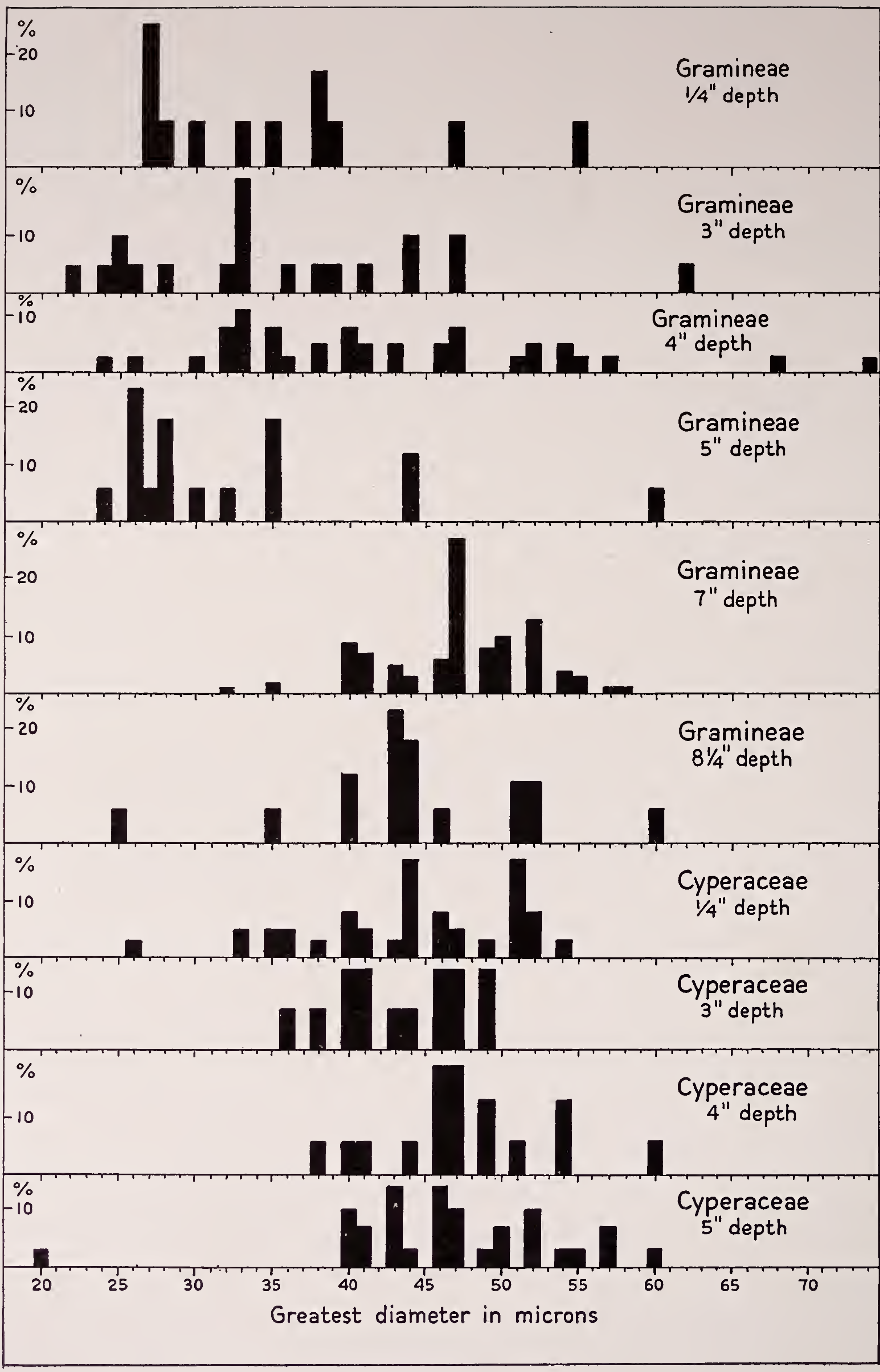

Fig. 7. Percentages of the different size classes of the pollen of *Gramineae* and *Cyperaceae*.

small amount of 2% aqueous gentian violet solution to the material on the slide stained only the pollen grains and greatly facilitated the counting.

The identification and counting of the pollen grains was performed with a Leitz binocular microscope at 100 and 440 power; slides were scanned methodically by means of a calibrated micrometer stage. The counting was continued until approximately 150 pollen grains of tree genera were counted for each sample. The non-tree pollen was identified as specifically as possible (generally only as far as the family), as it has not been proved as yet that tree pollen alone will be sufficient for the establishment of a detailed Post-glacial chronology for North America.[5] Pollen of the *Gramineae* (grasses) and *Cyperaceae* (sedges) was of such prominence in this peat that each grain counted was measured for its greatest diameter, and the percentages of the different size classes were plotted in a block diagram (Fig. 7), for the purpose of estimating the species involved.

The pollen percentages were based on the total tree pollen, which was taken as 100%. Table XII presents the pollen percentages, including the spores of vascular cryptogams and the pollen grains which could not be identified due to their poor state of preservation. The pollen profiles are shown in Figure 8. In the profiles the *Betula*, *Carpinus*, *Corylus*, and *Alnus* percentages were combined and shown as *Betulaceae* because the individual genera are in this case of little significance. Space did not permit the inclusion of profiles for the vascular cryptogams, which also are of little significance in this peat.

OBSERVATIONS

In the consideration of the pollen profiles of this eight-inch section of peat there are several indeterminate factors which must be kept in mind. The Lower Peat is buried beneath about thirty-three feet of heavy sediments, and must have undergone a greater amount of compression than peat at the same depth in a bog deposit. Therefore, it is difficult to estimate the vertical scope of these profiles in comparison with profiles from other bogs. The allochthonous character of the peat introduces difficulties in the interpretation of the pollen profiles, as there is a strong chance that the less resistant grains are poorly represented, and there is no definite means of telling the extent of the area from which the included pollen was received and whether conditions of sediment transportation were such that pollen was brought from the same areas throughout the deposition of the peat. The greatest obstacle to interpreting these profiles in an attempt to date this deposit is that there have been no detailed studies of the Post-glacial

[5] Bryan, Kirk, personal communication.

Table XII. Pollen Percentages for the Lower Peat

Genera	Depth in Section					
	Amorphous Layer	Stratified Layer			Top Black Layer	
	8¼″	7″	5″	4″	3″	¼″
Lycopodium	5.1*	1.3	1.1			0.8
Selaginella		3.9		1.0		
Filices	1.69	1.3			5.8	
Other spores†			3.3	1.9	3.7	4.3
Pinus	15.0	34.2	17.4	49.0	21.2	25.6
Picea	1.69				1.5	4.3
Tsuga	37.3	36.8	22.8	38.5	16.0	21.4
Gramineae	98.3	132.9	23.9	35.5	14.6	10.3
Cyperaceae	1.69	5.3	53.3	18.3	21.9	35.9
Typha			5.4			0.8
Populus	6.78	3.90	2.2			
Salix	5.1		2.2	1.9	2.2	3.4
Betula	5.1	2.6	7.6	1.0	2.9	4.3
Carpinus			4.3	1.9	2.9	2.5
Corylus					2.2	0.8
Alnus			2.2		1.5	
Quercus	13.5	7.9	25.0	1.9	27.0	18.8
Fagus	5.1		3.3	1.0	7.3	3.4
Carya		5.3			2.9	3.4
Platanus		1.3				
Almus			4.3	1 9	2.2	2.5
Chen.-Amrth.‡	5.1	5.3	8.7	15.4	40.1	12.8
Nyssa	5.1	2.6	1.1	1.9	1.5	2.5
Acer	5.1		7.6		8.0	5.1
Tilia		5.3				0.8
Fraxinus				1.0	0.7	0.8
Rosaceae		1.3		1.0	5.8	6.8
Polygonaceae			3.3			0.8
Plantaginaceae	1.69				8.0	
Compositae	3.4	5.3	10.9	5.8	4.4	0.8
Undetermined (based on total pollen)	19.0	5.0	32.0	16.0	22.0	16.7

* Percentages based on total tree pollen for each sample.
† Spores with the tri-radiate scar—vascular cryptogams.
‡ Pollen from members of the *Chenopodiaceae* and *Amaranthaceae*.

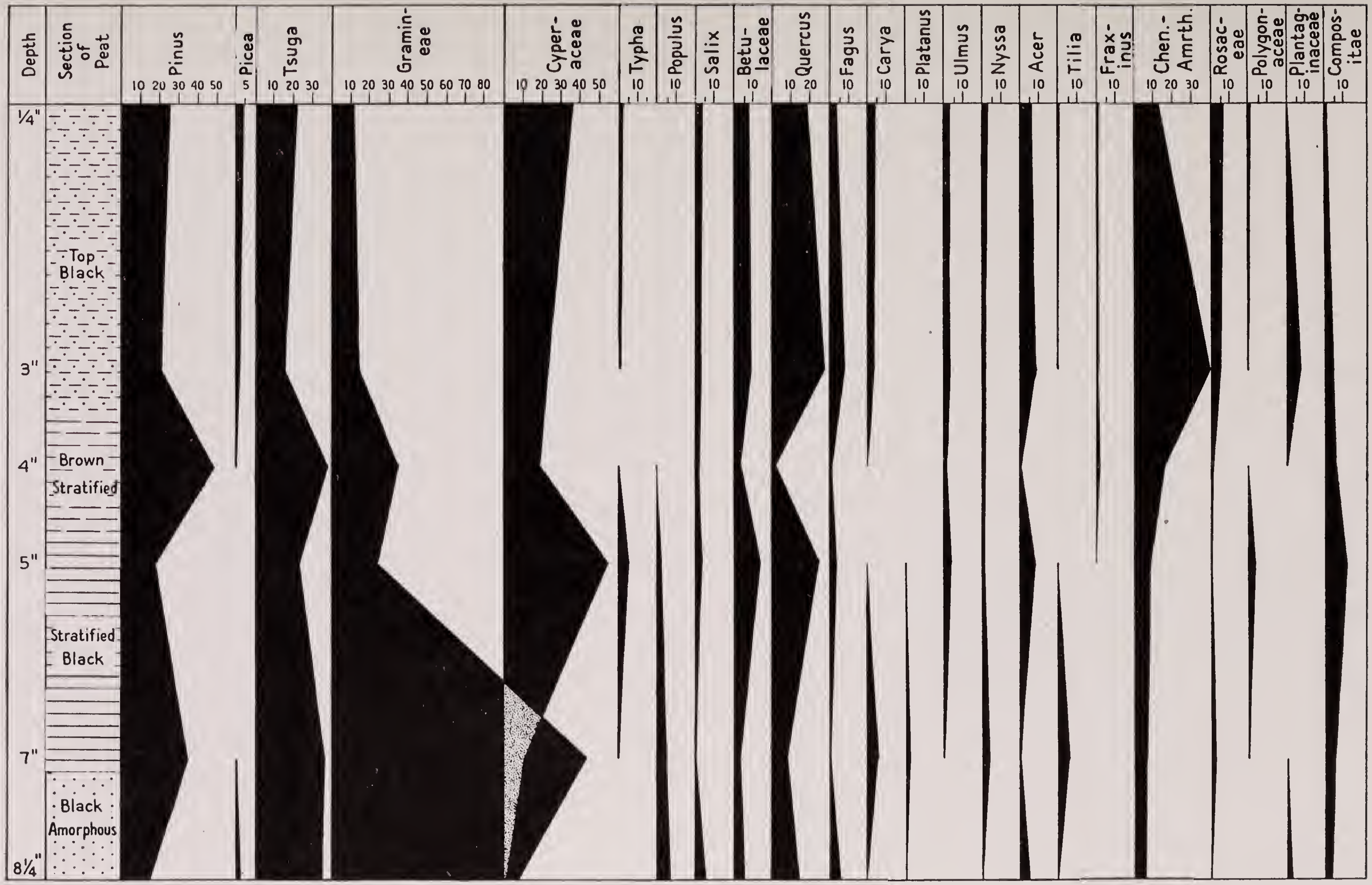

Fig. 8. Pollen profiles of the Lower Peat in the building excavation.

vegetational sequences in New England other than those of Deevey[6] in Connecticut. For the correlation of deposits such as the Lower Peat, it is necessary to have long profiles worked out at vertical intervals no larger than 1 decimeter with the critical stages studied at intervals of 1 to 3 centimeters.

Local profiles must represent averages of several individual profiles from one bog; regional profiles can be made by averaging the local ones. It is well understood that the charting of the Post-glacial pollen chronology for North America will require at least a decade yet, owing to the vast area and the complicated vegetational elements.[7] In view of these difficulties, the data from the Lower Peat are presented here as a record which must await further studies of pollen chronologies from the Massachusetts Bay region for complete interpretation.

From the profiles of the pollen from this deposit (Fig. 8) it will be seen that pine (*Pinus*) and hemlock (*Tsuga*) are dominant among the tree genera throughout the vertical extent of the peat. It is peculiar, however, to find hemlock showing fluctuations almost exactly parallel to pine. As hemlock is generally favored by a moister and pine by a drier climate, it is possible that this phenomenon is one indication of relatively stable climate during the interval represented here. Spruce (*Picea*) is poorly represented, but shows a slight increase in the upper levels. This rise in spruce may be attributed to the filling of neighboring bog land and the advance of spruce cover on them. Oak (*Quercus*), beech (*Fagus*), and maple (*Acer*) show precise parallelism, and alternate exactly with the fluctuations of pine. This balance of coniferous and hardwood forest elements is further evidence of a relatively stable climate for the duration of this interval. Hickory (*Carya*), tupelo (*Nyssa*), and basswood (*Tilia*) fluctuate in a generally parallel manner with their small maxima coinciding with pine maxima.

The fluctuations of the grasses and sedges may have been due in part to minor climatic changes, but it is likely that the pronounced maxima, at least, resulted from local ecological changes such as the destruction of forest areas by fire or wind, or the exposure of new areas for colonization by plants

[6] Deevey, E. S., 1939. Studies on Connecticut Lake Sediments. I. A Postglacial Climatic Chronology for Southern New England. *Amer. Jour. Sci.*, Vol. 237, pp. 691–724.

[7] The following references give detailed discussions of the status of pollen analytical studies in North America: Sears, P. B., 1937. Pollen Analysis as an Aid in Dating Cultural Deposits in the United States, pp. 61–66 in *Early Man*, ed. by George Grant MacCurdy. Sears, P. B., 1938. Climatic Interpretation of Postglacial Pollen Deposits in North America. *Bull. Amer. Meteor. Soc.*, Vol. 19, pp. 177–185. Cain, Stanley A., 1939, Pollen Analysis as a Paleoecological Research Method, *Bot. Rev.*, Vol. 5, pp. 627–654. Smith, Preston, 1940, Correlations of Pollen Profiles from Glaciated Eastern North America, *Amer. Jour. Sci.*, Vol. 238, pp. 597–601.

along the Charles River estuary. The generic and specific differences in the pollen of grasses and sedges are very small except for their sizes. In an attempt to estimate the genera and species involved in these two prominent groups, a block diagram of the size-classes of the grains was made (Fig. 7). As the greatest diameters of most pollen grains of a common grass species vary no more than 5 microns, the diagram demonstrates an assemblage of at least six or eight species. It is obvious that there was considerable variation in the different species present through the successive levels. The dominant sizes of grass grains in the 8¼ inch and 7 inch levels probably represent sweet vernal grass (*Anthoxanthum odoratum*, 37 to 46 microns in greatest diameter).[8] The dominant sizes in the four upper levels probably included red fescue (*Festuca rubra*, 30–32 microns), Kentucky bluegrass (*Poa pratensis*, 28–32 microns), orchard grass (*Dactylis glomerata*, 28–36 microns), annual bluegrass (*Poa annua*, 25–27 microns), and redtop (*Agrostis palustris*, 25–31 microns). The sedges show less diversity in the sizes of pollen grains, but the graphs exhibit some changes in the dominance of size classes. Unfortunately, sedge pollen types are even less well known than those of grasses, and the pollen of common species must be described before attempts to estimate the species by this method can be made.

At the 3 inch level there is a strong maximum of Chenopod-Amaranth pollen, undoubtedly due to a local ecological disturbance. There were two types of Chenopod-Amaranth pollen present in nearly equal numbers: although alike in appearance, one was 19 microns, and the other 30 microns. The small maxima of the *Polygonaceae*, *Plantaginaceae*, and *Compositae*, in view of their slight significance here, may be assigned to the same category of causes.

Two poorly preserved grains which appear to be tulip tree (*Liriodendron tulipifera*) pollen were found at the 5 inch level. As not all of the definitive characters could be seen, they were recorded among the undetermined grains.

DISCUSSION

The pollen profiles of the Lower Peat actually show only three pronounced maxima (in the *Gramineae*, *Cyperaceae*, and the Chenopod-Amaranth group); and these may be referred to local ecological changes. The profiles as a whole present a picture of a relatively static vegetation, as the differences between the maxima and the minima of the diagnostic tree genera (*Pinus*, *Picea*, *Tsuga*, *Quercus*, *Fagus*, *Carya*, *Ulmus*, *Nyssa*, and

[8] Sizes of grass pollen after Wodehouse, R.P., 1935. *Pollen Grains, Their Structure, Identification and Significance in Science and Medicine.*

Acer) are small. The most prominent change in the vegetation, as shown by the profiles, occurred between the 5 inch and 3 inch levels, but the coniferous tree-grassland flora shown at the 4 inch level may have resulted from a fire which destroyed the hardwoods. On the other hand, this configuration in the profiles may be due to a destruction of a large share of the pollen of the hardwoods, as it was noted during the counting of the grains from this level that the pollen of the deciduous tree genera was in poor condition.

Throughout the vertical extent of the profiles the floral assemblage retained the same general aspect presented by the vegetation of eastern Massachusetts at the present time. The fluctuations shown are of the type which can follow local ecological succession and topographical changes in New England without the influence of a change in climate.

A drier period during the deposition of the Lower Peat is indicated by the profiles at the 7 inch level where pine and hemlock are strong; grass attains a strong maximum (perhaps in part due to local phenomena, as mentioned above); poplar, willow, and the *Betulaceae* have decreased slightly; and oak, beech and maple have decreased correspondingly with small maxima for hickory, sycamore, tupelo and basswood. Moister periods are indicated at the 5 inch and 3 inch levels where pine and hemlock have decreased in favor of oak, beech, elm and maple. From the material now at hand it is impossible to interpret these changes as indicators of climatic change, but they are emphasized here as possible markers for future correlation with other profiles.

In view of the relatively static aspect of the vegetation, the similarity of the floral assemblage with that of eastern Massachusetts at present, and the lack of indubitable indications of drier climate than at present (e.g., a strong oak-hickory maximum), the author draws the tentative conclusion that the Lower Peat was deposited at a time since the last period of drier climate, which succeeded the Post-glacial climatic optimum. In consideration of the accumulation of silt overlying the peat, the age is assumed to be close to that of the last "xerothermic" period. In the terms of the chronology for northwestern Europe, the Lower Peat is tentatively assigned to the late Sub-Boreal or early Sub-Atlantic.

* * *

The author is grateful to Mr. Frederick Johnson for his assistance with information about the site, and to Dr. A. O. Dahl and Mr. W. C. Darrah for their helpful suggestions during the laboratory preparation of the material.

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CHAPTER 9

THE POLLEN ANALYSIS OF THE SILT AND THE TENTATIVE DATING OF THE DEPOSITS

Arthur S. Knox

POLLEN analysis has been used considerably in Europe as a means of dating geological events and paleontological and archaeological remains. Very little has been done along these lines in this country, largely because of the scarcity of information about climatic and floral changes that have occurred here. In addition there is no way of cross-dating these changes with geological phenomena, such as varves, or with archaeological remains of known age. It is believed, nevertheless, that because some of the facts are now available, a serious attempt can be made to use this method in this country as an adjunct to geological and archaeological investigations.

The pollen bearing deposits associated with the Boylston Street Fishweir offer an exceptionally good opportunity to use pollen analysis in an endeavor to date the sediments and the Fishweir itself. The method and the results are presented in this chapter, but because of the uncertainty of several of the factors involved in the discussion, it should be emphasized that the conclusions are tentative and await confirmation by future research.

ANALYSIS OF THE SILT

Location of Samples of Silt

Five samples were obtained by Dr. Richard Goldthwait from the silt in the building excavation. Three of these were cut out of the silt on the south wall of the trench from the following horizons: three inches above the Lower Peat (−15′5.09″), the top of Shell Layer 1 (−14′1.9″), in Shell Layer 2 (−12′11″). Two additional samples were obtained from other sections of the building excavation, one from above Shell Layer 2 (−10′2.4″), and a second from Shell Layer 3 (−6′.06″). These samples represent a cross section through the silt from immediately above the Lower Peat to Shell Layer 3. Unfortunately samples from intervening layers were not collected. Such would have permitted a more complete analysis of the silt, especially of the topmost stratum between Shell Layer 3 and the fill on the top of the section.

Method Employed for Concentrating Pollen from Silt

A preliminary examination of the silt samples from the excavation revealed that a small number of pollen grains and spores were present. Because of the scarcity of pollen it was necessary to use a special technique to concentrate these grains for analysis. The customary technique employed in concentrating the small quantities of pollen often found in silt includes the use of hydrofluoric acid. However this acid is difficult to use and there is a possibility that the process may destroy some of the pollen grains and spores. The writer has recently developed a new technique by which it is possible to separate easily and quickly spores and pollen from silt and other sediments. A modification of this method was employed in concentrating the above mentioned samples.

The silt was first boiled in a dilute solution of caustic potash to deflocculate it and to separate the pollen and spores from adhering material. It was then thoroughly washed, first with water and then with acetone. After drying, the sediment was passed through a 60 mesh sieve to free it from larger fragments of shells and stone. About ten grams of the fine material was then placed in a centrifuge tube containing a mixture of bromoform and acetone, the mixture having a specific gravity of 2.35. After thorough mixing, it was centrifuged which caused most of the inorganic sediment to settle out. The lighter organic components, including diatoms, sponge spicules, spores, and pollen were left floating on the top of the liquid. The lighter materials were decanted and the heavy residue was centrifuged again in order to recover any light organic material which might have settled out with the silt. The organic material was centrifuged a second time so as to free it from any remaining heavy particles. The resulting product was then filtered, thoroughly washed with acetone, and dried on a hot plate. The dried material was boiled in dilute caustic to expand the pollen grains and after mounting in glycerine jelly it was ready for study. In two cases, before the final treatment in caustic potash, hydrofluoric acid was used to get a greater concentration by dissolving out the sponge spicules, diatoms, and any remaining siliceous material. In most cases, however, this treatment was not necessary, because the concentration obtained by centrifuging was adequate for the present study.

Results of the Analysis

Between one hundred and fifty and two hundred pollen grains and spores from each sample of silt were identified, tabulated, and the percentage of each type, relative to the total tree pollen, was determined. The pollen and

spores of herbaceous plants were calculated, as is customary, as percentages of the total tree pollen.

It was found that the frequency of the pollen in the silt was low. On the basis of the content of the sample from Shell Layer 2, it was roughly estimated that there were approximately fifteeen to twenty thousand pollen grains and spores in ten grams of the silt. Although no attempt was made to determine the frequency of the pollen in the other samples of silt, it did not appear to vary much throughout the cross section.

TABLE XIII. POLLEN PERCENTAGES FOR THE SILT

	Above Lower Peat	Shell Layer 1	Shell Layer 2	Above S.L. 2	Shell Layer 3
Sphagnum	—	1.6	—	—	—
Filices	5.2	3.1	5.4	4.7	2.2
Pinus	20.8	29.4	42.0	48.1	22.7
Picea	.9	1.6	1.3	—	1.5
Tsuga	11.4	14.7	6.1	15.5	32.1
Cyperaceae	.9	5.4	.8	.8	.7
Gramineae	8.7	16.2	16.0	14.1	12.4
Populus	.9	—	—	—	—
Myrica	2.6	—	3.5	—	—
Carya	3.5	4.7	1.5	1.6	—
Ostrya	—	.8	—	—	.7
Betula	4.4	2.3	5.4	.8	3.7
Alnus	.9	.8	.8	—	.7
Fagus	5.2	3.9	2.3	2.3	2.2
Quercus	48.5	42.6	35.9	30.3	35.1
Almus	.9	—	.8	—	1.5
Chenopodiaceae	—	—	.8	1.6	—
Tilia	—	—	—	1.6	.7
Platanus	—	—	—	—	.7
Rosaceae	.9	—	—	—	—
Ilex	—	.8	—	—	—
Acer	—	—	.8	—	—
Other Spores	1.7	—	2.3	—	—

Table XIII lists the relative quantity and identification of the pollen in the several layers of silt. Figure 9, based upon the percentages in this table, indicates graphically, by means of pollen profiles, the fluctuations of each of the species or group of species identified in the cross section of the silt.

An examination of these profiles shows that the pollen of pine (*Pinus*), oak (*Quercus*), and hemlock (*Tsuga*) is the most abundant of the tree species

represented. The highest percentage of oak is found in the silt three inches above the Lower Peat. Above this there is a noteworthy decrease ending at the $-10' \, 2.4''$ level. Above this point there is a slight rise. The pine shows trends directly opposite to those of oak. Thus pine is at a minimum at the

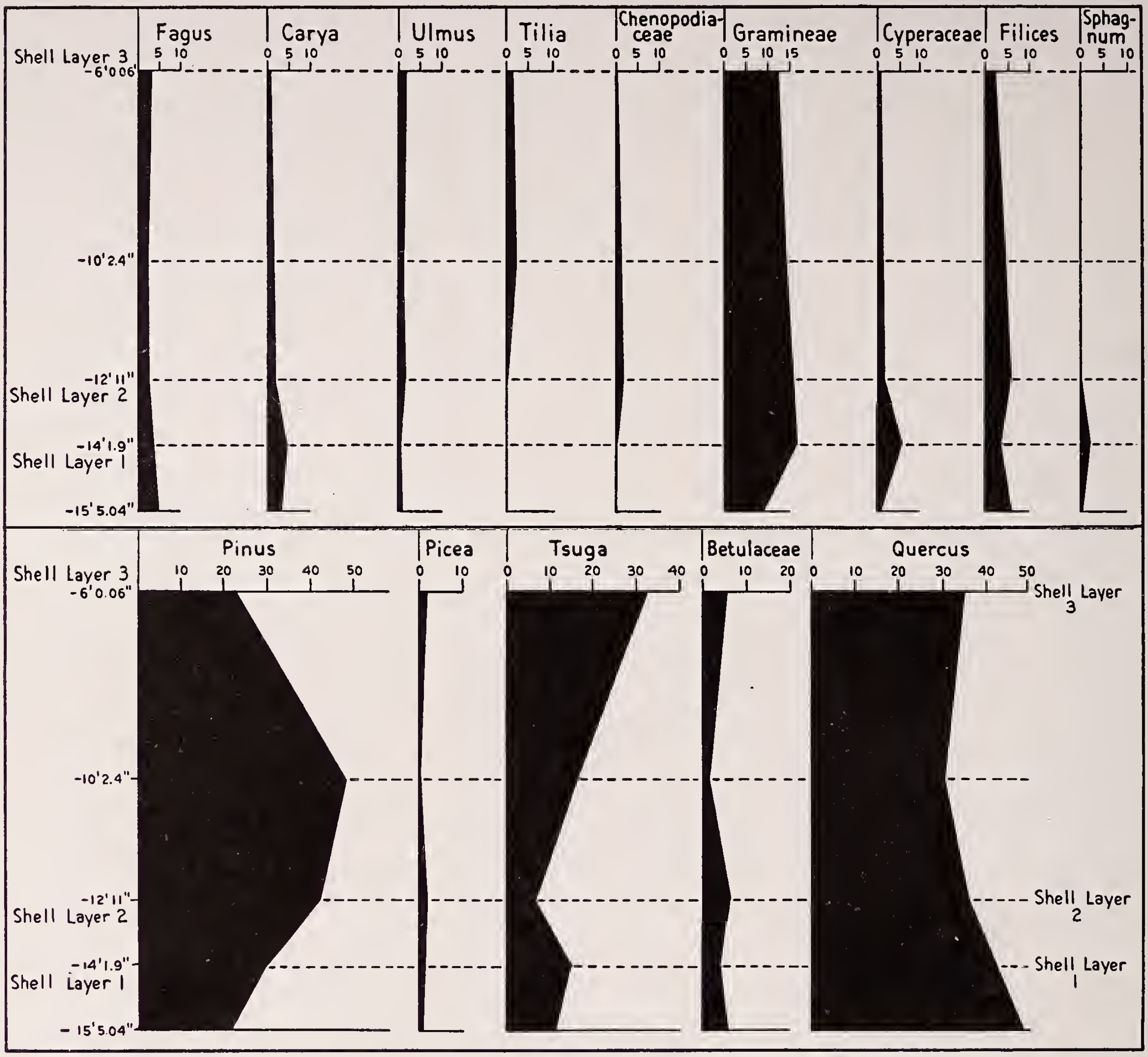

Fig. 9. Pollen profiles from the silt in the building excavation.

$-15' \, 5.09''$ level, when oak is at its maximum. At $-10' \, 2.4''$ the point where oak is at a minimum, pine reaches a maximum. Hemlock roughly parallels pine below $-10' \, 2.4''$. However, above this level, there is a continued and notable increase. During the increase in hemlock pine shows a sharp decline.

The members of the birch family (*Betulaceae*) and the spruce (*Picea*) also vary inversely with the pine; both reach their minimum at the time that pine is at its maximum. The greatest quantity of beech (*Fagus*) and hickory

(*Carya*) is found in the lower section of the silt. The amount decreases in the upper strata. The pollen of elm (*Ulmus*) occurs sapasmodically without well marked maxima.

Of the remaining pollen grains those of the linden (*Tilia*) are the only other tree pollen of importance in the silt. There are, however, a few grains from sycamore (*Platanus*), tupelo (*Nyssa*), and ash (*Fraxinus*), but these pollen grains occur spasmodically and except for the sycamore they are not abundant enough to enter into the pollen counts.

Unlike the trees, the herbaceous plants, with the exception of the grasses (*Gramineae*), are only sparsely represented in the samples examined. The grasses reach a maximum in Shell Layer 1 and this continues through Shell Layer 2. Above this layer the percentage of grass pollen slowly diminishes. The pollen of the sedges (*Cyperaceae*) is more numerous in Shell Layer 1 than in any of the other layers. Pollen of the chenopod group (*Chenopodiaceae*) is most common at $-10' 2.4''$, the location of the pine maximum. The spores of ferns are found without much variation in all samples. In several cases sporangia similar to some species of *Aspidium* were identified. These fern remains and the few spores of sphagnum that were noted, apparently had been washed in from brackish water marshes or fresh water swamps in the vicinity.

A comparison of the results of the above analysis of the silts with those obtained by Benninghoff from the Lower Peat[1] shows that fewer species are represented in the silt than in the peat. This is especially true of the herbaceous plants, the pollen and spores of which occur in much greater numbers in the peat than in the overlying silt. This difference may be the result of a change in climatic or of local environmental conditions which brought about a modification of the flora in the immediate vicintity. The evidence indicates, however, that the main factor was probably the destruction and modification of the swamp flora by a relative rise in sea level rather than a change in climate. Whether this can explain the change in the tree flora is open to question.

A comparison of the diagrams from the peat with those from the silt shows that a greater percentage of hemlock pollen is present in the peat than is recorded in the silt, on the other hand, the oak pollen reaches its maximum percentages in the latter. The presence of some stakes of hemlock in the Fishweir indicates that this tree was growing in the vicinity. Therefore this unusual abundance of hemlock grains in the peat may be merely a result of the proximity of a stand of hemlock which was eventually destroyed with the encroachment of salt water. The large percentages of

[1] Table XII, p. 100.

oak pollen as well as the large number of stakes and wattles of this tree in the Fishweir indicate the presence of extensive oak forests in the vicinity during the time of the deposition of the lower layers of silt. The presence of so much oak in the lower parts of the silt may reflect a climatic change subsequent to the time when the Lower Peat was formed and not merely a result of a local change in sea level.

CORRELATION OF THE DEPOSITS IN THE BUILDING EXCAVATION WITH THE PEAT IN THE WELLINGTON MARSH

When the pollen diagrams of the silt and the peat from the building excavation are combined they show floral and apparent climatic changes which took place during the development of the deposits. Because of the lack of data from the upper layers in the excavation, it is impossible to correlate these changes with ones of presumed later date found by the writer in other peat deposits in eastern Massachusetts. Therefore the relative time when the changes in the building excavation took place could not be determined directly with any degreee of certainty. In order to do this it was necessary to study a deposit which would give a complete picture of the changing flora, presumably due to fluctuations in climate, which have taken place in the Boston area during the last few thousand years.

In the selection of such a deposit two conditions are necessary. First, the history of the peat deposit chosen for investigation should be of sufficient length so that it would include the time involved in the formation of the deposits in the building excavation. Secondly, it is desirable to select a deposit close to the building excavation to preclude as much as possible variations of flora in the surrounding region. It was found, after some investigation in the Boston Lowland, that the Wellington Marsh fulfilled these requirements and so preliminary studies were made.

The Wellington Marsh

This marsh is located on the north bank of the estuary of the Mystic River above the Wellington Bridge in the City of Medford (Index Map Fig. 1). It lies about three miles from the building excavation. Pine stumps, still in situ and partly buried by the peat, are scattered over the surface of the marsh. These stumps are the remains of trees which grew upon the peat in historic times. Subsequent to their death, a thin layer of salt marsh peat, made up for the most part of *Spartina patens*, developed on top of the marsh. The presence of *Spartina*, typically a marine and brackish water grass, and also the presence of marine and brackish water diatoms and

foraminifera, indicate that in recent years the marsh has been inundated by the sea. The peat below this zone of *Spartina* is of fresh water origin. It has a maximum depth of twelve feet. The marsh is underlain by a layer of black amorphous peat with the maximum thickness of a foot which is similar in character to the Amorphous Layer of the Lower Peat in the building excavation. The amorphous peat in the Wellington Marsh often rests upon blue clay of unknown depth in a manner analogous to the situation in the building excavation. However, in some places a thin layer of fine sand or silty clay, never more than a few inches thick, is found directly below the amorphous peat. This layer contains fresh water diatoms. It appears to be of a different age than the barren blue clay below it.

Analysis of the Wellington Peat

With a Davis peat borer three holes were drilled in the Wellington Marsh. The holes were about one hundred yards apart near the center of the marsh where the peat is nine feet thick. Samples at one foot intervals from preliminary boring number 1 were analyzed. Pollen counts from these samples indicated that a more thorough study might supply data from which an approximate dating of the deposits in the building excavation could be attempted. In boring number 2, samples were taken at three inch intervals. Between three hundred and five hundred pollen grains and spores from each sample were identified and tabulated. The counts from the lower three and one quarter feet were checked by boring number 3. Samples from this hole were examined at three inch intervals and in critical places every inch. The results of the analysis of the marsh are shown in Figure 10. A study of the stratigraphy of the marsh, illustrated at the left of Figure 10, indicates that during its development there have been variations in the amount of moisture present. The marsh appears to have originated as a pond or lake in a depression in the blue clay. In this pond diatomaceous silt and clay were first deposited. Later sedge peat containing numerous pollen grains of cattail (*Typha latifolia*) and other water-loving plants began to accumulate. Above this zone the sedge was replaced by sphagnum, ferns, and other plants indicative of drier conditions. Eventually the surface of the bog became dry enough for the growth of shrubs such as alder and heath, and possibly trees. That this was an important dry stage is suggested by the thickness of this layer as well as by the decayed character of the peat in the upper part of this zone. Following this period of dryness, wetter conditions prevailed on the bog. This is shown by the reappearance of sphagnum in considerable abundance and eventually the development of sedge peat containing pollen of *Typha* and other water loving plants. From this point on,

the bog appears to have become dryer with minor fluctuations until eventually dwarf shrub peat reached its maximum development followed by the growth of trees upon the swamp. Some of these trees attained a diameter of over a foot with roots penetrating two or three feet into the peat. This suggests that before the marine invasion the swamp had become quite dry.

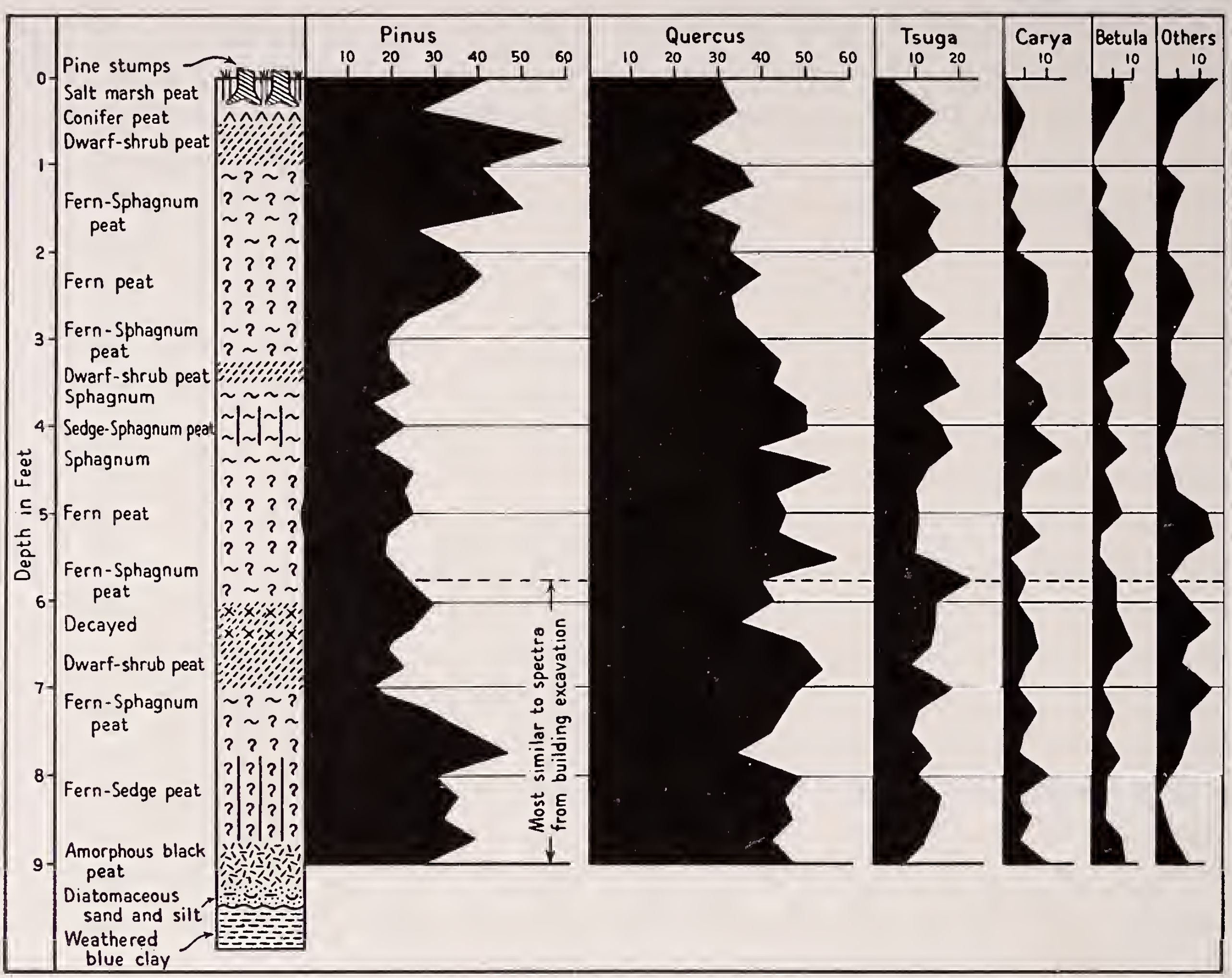

FIG. 10. Pollen profiles of trees from the Wellington Marsh, Medford, Massachusetts (Boring no. 2).

In general, therefore, the lower layers in the marsh deposit exhibit characteristics from which dry conditions are inferred. The middle strata of peat show evidence which indicate an increase in the amount of moisture. This was followed by a return to relatively dry conditions. These changes are further brought out by an analysis of the pollen profiles.

These profiles show that there is a well marked pine maximum near the bottom of the section at the seven foot nine inch level. A secondary maximum occurs a short distance above, at the six foot level. The latter maximum occurs during the period when the marsh was covered with dwarf

shrubs and therefore shows signs of desiccation. This interval is followed by a period of subaerial decay. It is also possible that trees were present on the surface of the marsh at this time, although no stumps were encountered. As a result of this period of dryness, the pollen grains in this layer are not as well preserved as in other parts of the deposit and are relatively scarce. Many of the pollen grains are fragmentary, especially the larger ones, such as pine, which were in many cases represented merely by detached wings or bladders. It is probable that, as a result of desiccation at this level, pine is somewhat under-represented and actually the percentages for this tree should be higher than are shown in the profiles. There is another very prominent pine maximum at the nine inch level at the top of the section where the marsh had become dry enough for the growth of trees. However, it is quite likely that in the upper layers of the deposit, pine is over-represented because of the presence of these trees near or upon the marsh.

The profiles also show that the percentages of oak pollen run counter to those of the pine. There is an oak minimum at the seven foot nine inch level at the time of the pine maximum, and another minimum at the six foot three inch level just below the secondary pine maximum. A prominent oak maximum may be noted at the six foot nine inch level. This lies between the two pine maxima. Above the secondary pine maximum, beginning with the six foot level there is a general increase in the percentages of oak. This increase reaches two maxima, one at the five foot six inch level and a second at the four foot six inch level. At the latter horizon the peat shows indications of increasing wetness. This high percentage of oak continues until about the three foot level. Above this, the peat reveals dryer conditions and there is a decided falling off in the number of pollen grains of this tree.

This analysis of the Wellington Marsh shows that pine maxima and oak minima occur at horizons when the peat shows signs of desiccation, while on the other hand, oak maxima and pine minima occurred at times when wetter conditions prevailed. This suggests that in the Boston area at least, pine maxima and oak minima are indicative of dry climatic conditions, and pine minima and oak maxima indicate a wetter climate.

Studies of other peat deposits in eastern Massachusetts by the writer show that this hypothesis is valid. The profiles of various bogs demonstrate that changes in relative percentages of pine and oak pollen are the most important indicators of trends of climate in this area, especially during the last few thousand years. The data from several peat bogs on Cape Cod show, without exception, that the relation between pine and oak and dry and wet horizons in the peat were the same as that found in the Wellington Marsh.

Methods of Correlation

With this picture of the floral and climatic changes of the Boston area as recorded by the Wellington peat, it is possible to attempt a correlation of this deposit with that of the Fishweir. Two methods are open. The first of these is the method commonly employed by European workers. This involves the use of significant tree pollen such as the linden, spruce, hornbeam (*Carpinus*), and other species, which appear or disappear in the sequence. The appearance or disappearance of these floral elements is the main basis for the division of post-glacial chronology into stages or zones, which are dated by archaeological or geological data.

A comparison of the profiles from the Wellington Marsh with those from the building excavation indicates that this method cannot be employed because there are no significant elements in the flora which can be relied upon to make an adequate correlation in this way. It appears that the forests existing in the vicinity of Boston while the Fishweir was built and used were not greatly different from those that existed in the area up to the past century. The pollen analyses indicate that during the last few thousand years none of the elements of the flora of which we have any knowledge entirely disappeared and that no new elements have become established.

The only other way by which correlation between the two deposits can be made is by comparing the fluctuations in the pollen profiles. This method has been used in England by Godwin and in this country by Hansen.[2] This method is based upon the fact that peat deposits in a given area show similar fluctuations in their pollen profiles. The closer the deposits are to each other, the more similar they should be, because the pollen falling upon them will be derived largely from trees growing in the same general area. On the other hand, if the two deposits are widely separated, the areas from which pollen is derived will not be the same, although the climate and other conditions may be similar. There are, however, always differences in the pollen profiles of peat deposits no matter how close they are together and even if they are from different parts of the same bog. This is largely due to the local distribution of the flora. Nevertheless, the main trends in the development of the forest flora may be determined.

In comparing the pollen profiles from the Wellington Marsh with those

[2] Godwin, H. and M. E. Godwin, 1933. "British Maglemose Harpoon Sites." *Antiquity*, Vol. 7, pp. 36–48.

Godwin, H. and L. Newton, 1938 "The Submerged Forest at Borth and Ynyslas, Cardiganshire." *New Phytologist*, Vol. 27, No. 4.

Hansen, H. P., 1937. "Pollen Analysis of Two Wisconsin Bogs of Different Age." *Ecology*, Vol. 18, No. 1, pp. 136–148.

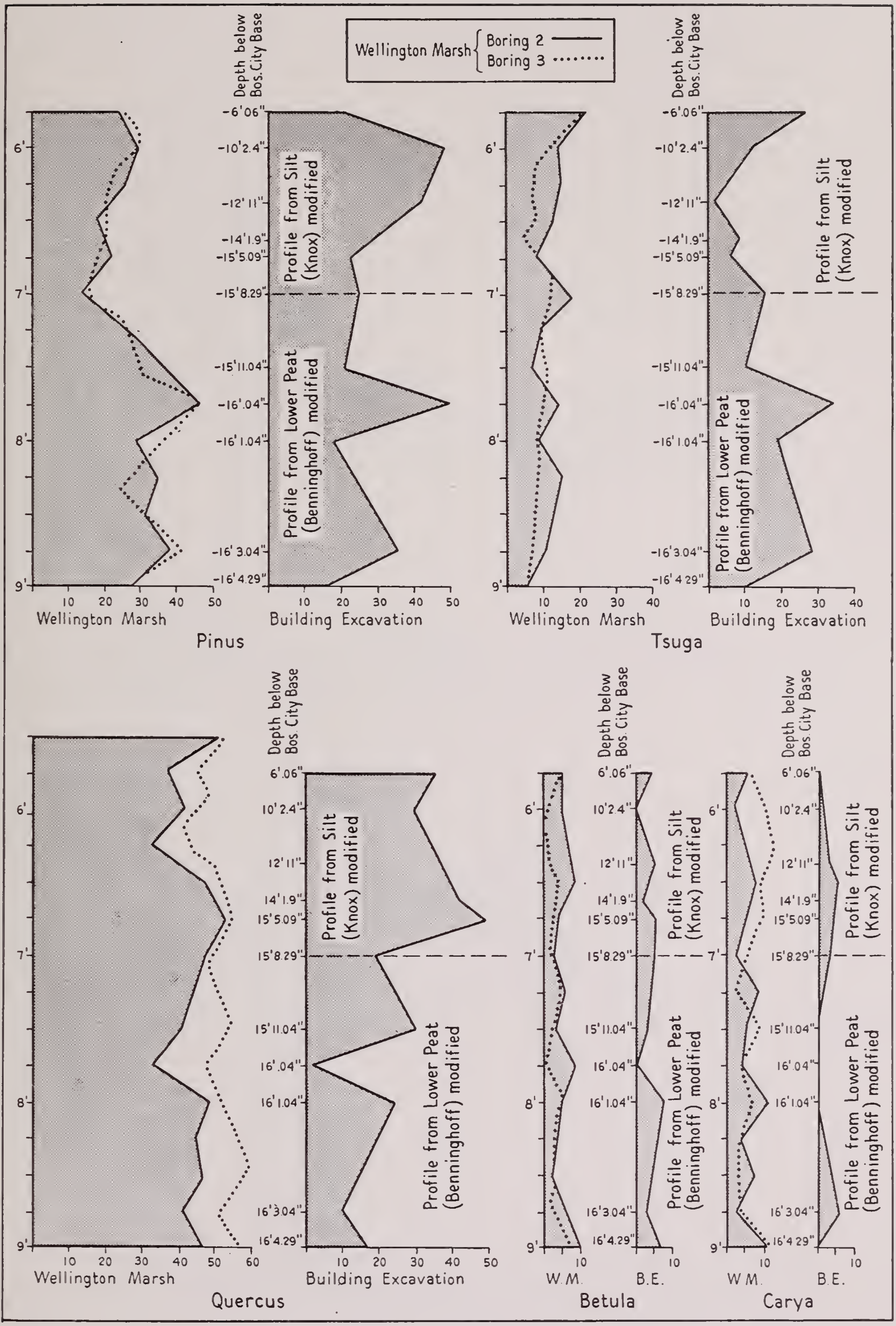

FIG. 11. Correlations of pollen profiles of trees from the Wellington Marsh and the building excavation.

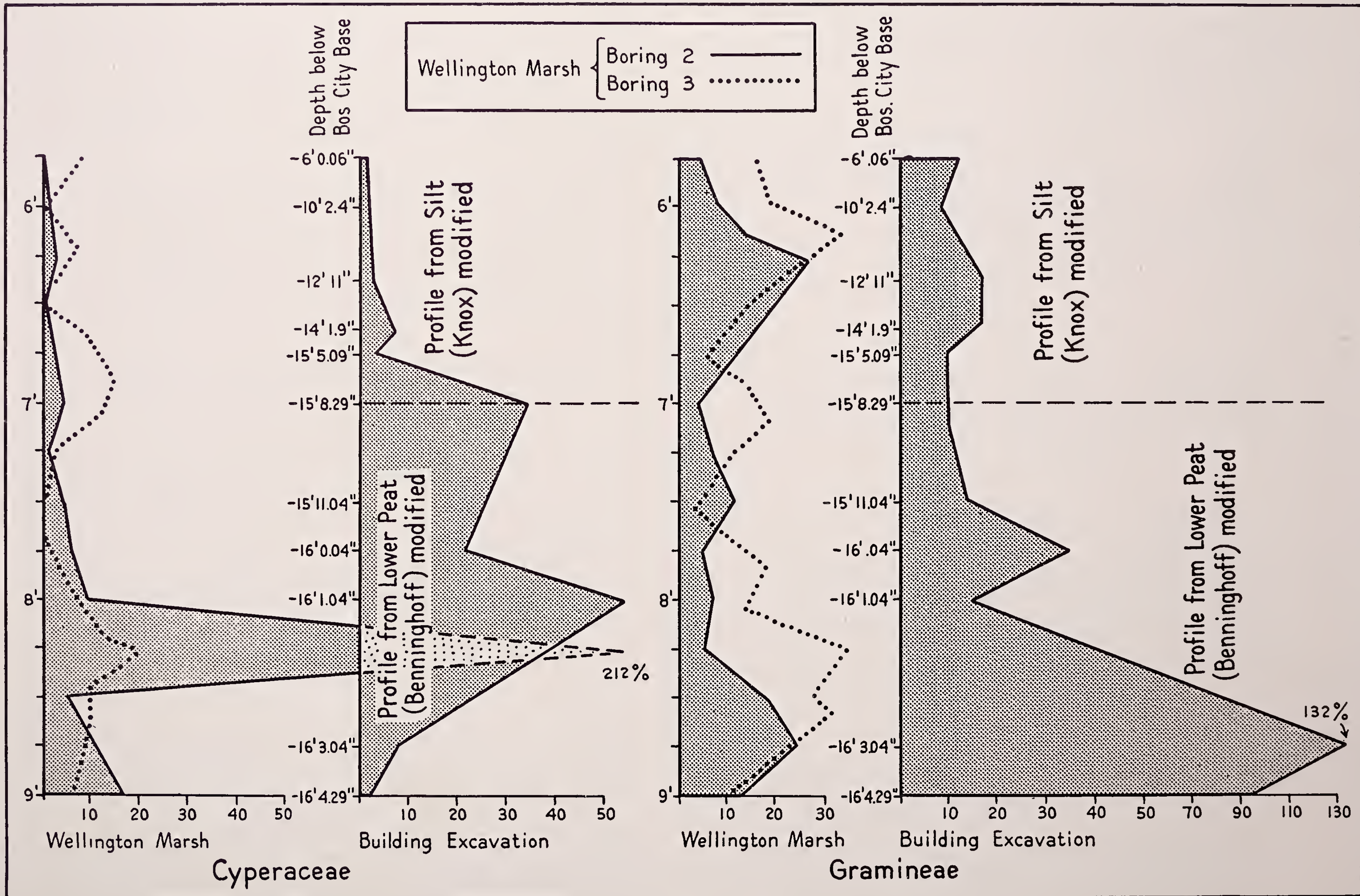

FIG. 12. Correlation of pollen profiles of *Cyperaceae* and *Gramineae* from the Wellington Marsh and the building excavation.

from the building excavation, the differences in the character of the two deposits and in conditions under which they were laid down should be recognized. The peat from the building excavation has probably been compacted to a greater degree than that from the Wellington Marsh. Also the variable rate of silt deposition in the building excavation is quite different from the process of peat accumulation which took place in the Wellington Marsh. Thus it appears that these factors would bring about a distortion of the pollen profiles from the building excavation and so the profiles from the two deposits cannot be "matched" until allowance for this distortion has been made.

The Correlation of the Two Deposits

With these considerations in mind, a quantitative comparison was made between the pollen profiles from the Wellington Marsh and those from the building excavation. On the basis of the number of pollen grains and of the different species and their fluctuations, the profiles from the lower three feet three inches of the Wellington Marsh (−5′9″ to −9′) are found to be most similar to those from the peat and silt in the building excavation. The correlation of these two deposits, including allowances for distortion, is shown in a series of diagrams (Figs. 11 and 12). These show the fluctuations of percentages of pollen of the significant trees as recorded from the two localities. The diagrams indicate that for comparative purposes pine is probably the most significant. This tree is a prolific producer of pollen and the grains are often carried by the wind for considerable distances. Therefore, fluctuations in the amount of pine pollen in the atmosphere should be reflected in the two deposits at the same time. On the basis of this assumption, the pollen profile of the pine from the building excavation was matched to that of the Wellington Marsh. Because of probable distortion the profile was lengthened in some places and shortened in others. As this modification of the profile progressed constant reference was made to fluctuations of other elements in the flora. This modified profile of pine was thus used as a basis for the construction of the others. The modification of the profiles from the building excavation by changing the original scale of depths only affects the time relations; it does not change the magnitude of the percentages of pollen. Thus the inferred sequence of climatic changes is unmodified.

Upon comparing the profiles of the most abundant tree pollen from the Wellington Marsh and the building excavation it will be seen that they closely parallel each other. The parallelism of the trends in the profiles of oak and hemlock from the two deposits are too similar to be accidental.

This parallelism is less apparent in profiles of trees which are represented by lesser quantities of pollen. The latter situation is not surprising because it is probably due to local influences. It has been found that bogs situated only short distances from each other may show conspicious differences in some of their pollen profiles. In such cases the main trends of the more abundant tree species are usually approximately parallel. The agreement between the profiles from the two deposits is unusually close especially when the degree of agreement is compared to similar correlations which have been used to prove that other bogs are contemporaneous with each other. The development of parallel profiles from the Wellington Marsh and from the building excavation permits the hypothesis that the lower sections of the Wellington Marsh and the cross section of the building excavation up to $-6'$ .06″ developed at the same time. Points on the profiles which are contemporaneous may be located by drawing horizontal lines through the diagrams.

Evidence of a Contemporaneity Which May Be Deduced from the Sequence of the Deposits

The sequence of deposits in the marsh is similar to that of the Lower Peat in the building excavation. Both rest upon blue clay which is separated from the main portion of the peat by a black amorphous layer. However, no diatomaceous silt or clay similar to that found in places in the Wellington Marsh is found below the Amorphous Layer of the building excavation. In the peat above the clay in both places, there is a considerable abundance of grass and sedge pollen with the sedge reaching its greatest development just before the first pine maximum (compare Fig. 12 with Fig. 11). Above this there is a marked difference in the two accumulations probably as a result of the marine invasion of the Charles River estuary. There appears to have been a sedge mat present soon after or during the formation of the Amorphous Layer in the Wellington Marsh. Whether or not a similar floating mat existed during the formation of the Amorphous Layer or the Lower Peat in the building excavation cannot be definitely determined. Such mats, however, are sometimes found in close proximity to the ocean in fresh water lagoons. If such deposits sink and become grounded by the weight of the accumulating plant remains or by silt brought in by the tides, they will eventually come to rest upon somewhat uneven and in most cases sloping surfaces. This may be the reason why the Lower Peat was formed upon a slope. The amorphous layers in both the Wellington Marsh and the building excavation are very similar in character to the peat that often accumulates below sedge mats. Such peat is largely composed of decayed material that

has dropped down from above. It is usually fine grained, structureless, well decomposed, and nearly black in color. If, however, a sedge mat did exist during the formation of the Lower Peat it seems that it probably was contemporaneous with that of the Wellington Marsh.

Other Evidence of Contemporaneity Between the Wellington Marsh and the Building Excavation

Further evidence of the probable contemporaneity of the two deposits may be found by comparing the modified profiles from the building excavation (Figs. 11, 12) with the original pollen profiles from the site (Figs. 8, 9). If the modified profiles of the Lower Peat (Figs. 11, 12) are compared with the original profiles as supplied by Benninghoff (Fig. 8), it can be seen that the modification of the original profiles, in order that they may be correlated with profiles from the Wellington Marsh, produces very little distortion of the original. The distortion which is shown in the modified profiles may be used to demonstrate, tentatively, two possible developments: 1) the upper layers of the Lower Peat were deposited at a more rapid rate than was the peat in the Wellington Marsh; 2) there has been less compression of the upper layers of the Lower Peat. Regarding the lower layers of the Lower Peat the reverse is true. If the development of the Wellington Marsh and the deposits in the building excavation were not contemporaneous there would be much greater distortion of the pollen profiles of the Lower Peat. Because of the relatively small amount of distortion in these profiles there is even a greater probability that the two deposits developed at the same time.

The accumulation of silt in the Charles River estuary would differ considerably in rate from the growth of peat in the Wellington Marsh. The comparison of Figure 9 with Figures 11 and 12 shows an amount of distortion which would be expected.

Evidence from the Amount of Compression of the Lower Peat

A final indication that the peat in the Wellington Marsh may be contemporaneous with the deposits in the building excavation is indirectly inferred from a calculation, based on measurements in the pollen profiles, of the amount of compression of the Lower Peat. There is no doubt that the Lower Peat has been compressed by the overlying sediments. The silt had been compacted as is shown by the deformation of the stakes and wattles. Certainly, the weight of the silt must have compressed the peat. The amount of compression may be estimated from the pollen profiles. The depth of the Lower Peat is eight and one quarter inches (Fig. 8). The modi-

fication of the profiles from this layer, for the purpose of matching them to the profiles from the Wellington Marsh, expanded this distance to exactly twenty-four inches (Figs. 11, 12). These figures indicate that the Lower Peat has been compressed to about one-third its original thickness. In addition to these figures, the pollen profiles of the Lower Peat show marked fluctuations of percentages even at inch intervals. Such fluctuations are not found in normal peat deposits unless these were formed unusually slowly or else were considerably compressed. The amount of compaction of the peat would depend upon several factors. In this case the most important would be the amount of silt present. Peat containing a large amount of silt would be compressed less than pure peat.

There is little information available as to the amount peat can be compressed under a natural load. Peat artificially pressed under considerable force in peat machines may loose two thirds or more of the volume it had when it was placed in the machine. This figure is, however, not very satisfactory because much of the water in the peat when it was in the marsh is lost before the peat is placed in the pressing machine. Because the amount of compression will depend upon the amount of water expelled from the peat the above figure appears to be too low.

Douglas Johnson,[3] upon examination of salt marshes that have been overridden by beach deposits of considerable thickness, notes that such silty deposits of peat were compressed to one-third or one-quarter of their original thickness. This peat does not appear to have been much different from the Lower Peat, because it was formed in a similar environment and under similar conditions. The figure suggested by Johnson is remarkably similar to the amount of compaction calculated for the Lower Peat.

As was pointed out, the amount of compression will depend upon the amount of silt present. In the Lower Peat one would expect, because of the large amount of silt in the upper layers, that the amount of compaction here would be less than in the lower layers of the deposit where there is much less silt. Interestingly enough a comparison of depths in Figures 11 and 12 shows that while the total compression of the layer was about two thirds, the separate layers were compressed different amounts. The lower layer of the peat was apparently compressed to less than one quarter of its original thickness, and the upper layer was only compressed about one half. Because the calculated amount of compression of the Lower Peat seems reasonable and is supported by other evidence, it strongly suggests that the data from which the calculations were made are not radically wrong and

[3] Johnson, Douglas, 1925. *The New England Acadian Shoreline.* New York, p. 529.

that the deposits in the building excavation and Wellington Marsh are therefore contemporaneous.

Although all the above observations seem to indicate that the lower part of the Wellington Marsh peat, and the Lower Peat and silt are about the same age, it should be pointed out that this conclusion has been based upon but one peat deposit and one series of samples from the building excavation. If several peat deposits in the general neighborhood of the building excavation and more than one series of samples from the excavation had been available, the contemporaneity could have been more clearly ascertained.

THE DETERMINATION OF THE AGE OF THE DEPOSITS

The pollen profiles from the building excavation and from the Wellington Marsh show that the climatic conditions as well as the flora of the Boston area during the period the Fishweir was in use were not much different from those of the present time. If the correlation of the two deposits is valid, it shows that the structure was in use during a long dry period during which the Wellington Marsh gradually dried up until shrubs and possibly trees began to grow upon the surface. This period of dryness was apparently terminated rather suddenly by an increase in rainfall and storminess which occurred about the time that the Fishweir was abandoned. At this time the Wellington Marsh shows signs of retrogression with a renewed growth of sphagnum and other plants indicative of wetter conditions. This period of increased rainfall apparently lasted until comparatively recent times, when this marsh as well as other bogs in eastern New England returned to dryer conditions.

The date of the period of transition from a dry climate to one of increased rainfall is important because it appears to offer a basis upon which the age of the Fishweir and the associated deposits may be determined.

Similarity of Climatic Changes in Europe and Eastern North America

Most students of climatology believe that the main changes of climate during post-glacial time were contemporaneous throughout a large part of the Northern Hemisphere. C. E. P. Brooks, an outstanding authority on climate says, in regard to these changes in North America: "In the post-glacial period, the peat-bogs show a succession of wet and dry periods which closely resembles the Scandinavian succession. The changes in North America cannot be dated by archaeological evidence, but there seems no reason to doubt the approximate synchronism of corresponding stages in North America and Scandinavia, especially as the two areas seem to be linked up

to some extent by deposits in Iceland and Greenland. This would give a long dry period during the third and second millennia B.C. in Eastern North America, which fits excellently with the lake records."[4]

Professor Kirk Bryan of Harvard also states that although there are no a priori reasons for believing that the climatic changes in North America and Europe were exactly similar, yet the fact that the minor cyclic changes are found to be parallel in both places at the present time, strongly suggests that long period fluctuations were probably also similar and synchronous.[5]

This parallelism of the climatic changes in Europe and North America is shown by a comparison of the results of pollen analyses of European and North American peat deposits, including those of New England. This shows that the main post-glacial climate fluctuations in these two places are very similar in character.

According to the Scandinavian chronology of Blytt and Sernander[6] post-glacial time may be divided into six divisions based upon climatic evidence. Von Post[7] has simplified this time scale from the evidence of peat deposits. He has divided post-glacial time into three periods. The ideas of these students are summarized below.

Blytt and Sernander	Von Post
6. Recent 5. Sub-Atlantic Cool and moist	3. A period of decreasing warmth with a decrease in the number of heat loving trees and the development of the elements of the present forest.
4. Sub-Boreal Warm and dry 3. Atlantic Warmer and wet	2. A period of maximum warmth and the culmination of the development of warm climate trees.
2. Boreal Warm and dry	1. A change to a warm period with an increase of heat-loving trees.
1. Pre-Boreal Arctic and subarctic	

Two layers of stumps are often found in European bogs. One of these is located in the lower parts of the older peat deposits and is generally considered to be of Boreal age. The second layer marks the transition from warm to cool climatic conditions and, according to Blytt and Sernander, developed during the Sub-Boreal period.

[4] Brooks, C. E. P., 1926. *Climate Through the Ages.* London, pp. 391–392.

[5] Bryan, Kirk, 1932. "Paleoclimatology in North America as a result of the study of peat bogs." Zeitschrift für Gletscherkunde, Bd. XX, Heft 1/3, p. 79.

[6] Sernander, R., 1908. "On the evidences of Postglacial changes of climate furnished by the peat-mosses of Northern Europe." *Geol. Fören. Förhandl.* Bd. 30, Haft. 7, pp. 465–473.

[7] Von Post, L., 1930. "Problems and Working-lines in the Post-arctic History of Europe." *Rept. Proc. 5th Intern. Bot. Congr. Cambridge,* pp. 48–54.

In eastern New England it has been found that the sequence of climatic changes is very similar to that outlined above. The older peat deposits had their origin in ponds and lakes located on glacial till or outwash from the melting ice. These ponds gradually dried up during a long period of desiccation until eventually trees were able to grow upon the accumulating vegetable material. This is indicated by the presence of tree stumps in situ in all of the older bogs in eastern Massachusetts that have been examined. At this level spruce pollen, which is very common in the lower levels during the pond stage, suddenly disappears and the pine pollen reaches its maximum. At the same time the pollen of heat-loving trees begin to appear in increasing numbers. This change from spruce to pine forests was therefore probably the result of a general rise in temperature, and a change to dry conditions. This period is, in position and character, very similar to that of the Boreal of Europe.

This dry period was followed by an increase in precipitation, which killed the trees and resulted in the development of sedge and sphagnum peat above the tree stumps. At the same time there appears a gradual increase in the percentages of pollen of deciduous trees, such as oak, tupelo, and beech, but pine pollen declines. Many new and rare floral elements also appear. Eventually the percentages of pine pollen reach a minimum and in some places it almost disappears. It is at this point also that the frequency of tree pollen in most of the New England peat deposits examined reaches its maximum. From this description it can be seen that this period is very similar to that of the Atlantic period of Blytt and Sernander, and von Post's second period.

This long, wet and warm period was followed by a second dry period, which is not as well marked as the older. Although shrubs appeared on the surface of the bogs during this time, tree stumps have been encountered at this horizon in only a few localities. This period of dryness witnessed a return of high pine percentages, a decrease in the number of deciduous tree pollen, the disappearance of some of the rarer species, and a falling off in the general frequency of tree pollen. This period appears to be equivalent to the Sub-Boreal Period in Europe.

This period of desiccation was followed by a sudden change in climatic conditions resulting in the retrogression of the peat bogs to a wetter stage. This was accompanied by an increase in oak and a decrease in the percentages of pine. At the same time further north in southern Maine, spruce reappeared suggesting that the climate was not only wet but also somewhat cooler. This period, which apparently lasted for several hundred years, is similar in character and position to the Sub-Atlantic. At the present time

there are indications of a return to dryer and possibly warmer conditions.

A comparison of the above sequence with that found in the Wellington Marsh and the building excavation shows that the dry period indicated in the two localities is in no respect similar to the older period as recorded in the New England bogs. The data does strongly suggest that it is equivalent to the second of these periods.

An analysis of the pollen profiles from the Wellington Marsh and the building excavation shows that following the apparent dry period the climate became wetter and probably cooler than the climate of Boston at the present time. There is no evidence in the pollen bearing deposits of either locality that indicates that a climatic optimum occurred during the time of their formation.

There is some evidence, nevertheless, that suggests that optimum conditions preceded the building of the Fishweir. There is, in general, a gradual decrease in the number of the pollen grains of the rarer tree species such as the linden (*Tilia*) and the tupelo (*Nyssa*) from the bottom of the Lower Peat upward. Although these forms are occasionally found in the silt and in the upper levels of the Wellington Marsh peat, they do not have as great a representation as in the Lower Peat and in the lower levels of the Wellington deposit. This may mean that the climate began to deteriorate soon after or during the formation of the Lower Peat. This condition continued during the deposition of the silt with a slight improvement during the formation of Shell Layer 2, which occurred about the same time as the secondary pine maximum. The same situation was found in the Wellington Peat. The pollen profiles show a marked deterioration after this time. This change is supported by the evidence of the diatoms and mollusks.

A further indication that this dry period is equivalent to that found in other New England peat deposits is the fact that during this time the pine shows two maxima. These are shown in both the Wellington Marsh and the deposits of the building excavation. This peculiarity has been found in other deposits in New England at this horizon and it seems to be a more or less persistent feature. A similar feature has been found in European bogs. According to the Scandinavian succession worked out by Fromm there are two pine maxima at this time, one about 2600 B.C. and the other about 1000 B.C.[8] Similarly Grandlund by a study of the amount of decay of sphagnum peat notes that there were really two dry periods during this period, one about 2300 B.C. and the other about 1200 B.C.[9]

[8] Fromm, E., 1938. "Geochronologisch datierte Pollendiagramme und Diatomeenanalyses aus Ăngermanland," *Geol. Fören. i Stockholm Förhandl.*, Vol. 60, pp. 365–381.

[9] Grandlund, E., 1932. De Svenska Hogmossamas Geologi. *Sverig. Geol. Unders. Afh.* No. 373.

From the above discussion it appears that the sequence of events recorded by the New England bogs is remarkably similar to those found in Europe and furthermore there is some evidence for believing that the dry period which prevailed during the time the Fishweir was in operation is equivalent to the Sub-Boreal of Europe.

Dating of the Deposits in the Building Excavation

Although the climatic changes in eastern North America and Europe appear to be parallel, there is however some question whether or not they were exactly synchronous. The fact that minor changes at the present time are parallel and synchronous suggests that the longer climatic cycles occurred on the two continents at the same time, particularly in view of the general belief that these changes were due to astronomic developments. However it is difficult to prove this synchronism, because at the present time there are no accepted means for correlation. Nevertheless, there is some indirect evidence for the assumption that these climatic changes were synchronous.

It has been pointed out previously that the peat bogs of New England show indications of a recent change of climate to somewhat drier conditions. If climatic changes are synchronous then similar changes should be found in European bogs. This is the case. Signs of desiccation have been noted in the upper horizons of many bogs in England and northwestern Europe.[10]

Another indication that suggests that the climatic changes were synchronous is based upon estimates of the date of the change of climate from dry and warm to wet and cool, which occurred at the end of Sub-Boreal time. According to the Scandinavian chronology the date of this change based upon detailed archaeological and geological data is about 1000 B.C. According to De Geer's figures derived from the study of varves the change appears to have occurred just after 1200 B.C.[11]

Sears, in this country, has attempted to date the dry period, equivalent in position to the Sub-Boreal, in the peat deposits of Ohio.[12] He has done this by making observations on the rate of peat accumulation. Samples of peat were sectioned and yearly laminations were found to be present. By counting these layers it was found that the rate of peat accumulation was about

[10] Godwin, H., 1940. "Pollen Analysis and Forest History of England and Wales." *New Phytologist*, Vol. 39, no. 4, p. 398.

[11] De Geer, G., 1940. "Geochronologia Suecica Principles." *Kungl. Svenska Vetenskapsakademiens Handlingar.* Tredje Serien Band 18. No. 6, p. 40 and Plate 87.

[12] Sears, P. B., 1932. "The Archaeology of Environment in Eastern North America." *Amer. Anth.*, Vol. 34, pp. 610–622.

Sears, P. B. and E. Janson, 1933. "Rate of Growth of Peat in the Erie Basin." *Ecology*, Vol. 4, pp. 348–355.

four inches in a hundred years. This figure was checked by observing the depth at which conifer needles first appeared in the bog at a place where larch and spruce were growing. The age of the trees from which the needles had come was determined by means of their tree rings. It was calculated that it took between twenty and thirty years for an inch of peat to form. From these figures it was found that the date of the recent dry period indicated by the peat bogs in eastern North America was about 1300 B.C., a figure which is very similar to De Geer's estimate based on varves.

According to Huntington's study of the tree rings in the Sequoias of western United States, this change of climate occurred about 1200 B.C.[13] Although this figure is based upon data of questionable accuracy it seems to fit in well with the data obtained by Sears in this country and De Geer in Sweden. Therefore although the exact date of the transition is not definitely settled, yet there is evidence for the belief that the above dry period ended about 1200 B.C. in this country and in Europe. In dating the Fishweir this figure is tentatively adopted, but it may need to be changed as more data becomes available.

There is evidence for believing that the date 1200 B.C. marked the end of the dry period shown in the study of the Wellington Marsh as coinciding with the six foot level. From this date the average rate of peat accumulation in the Wellington Marsh was estimated to be 2.25 inches per century, because nearly thirty-two centuries were required to produce seventy-two inches of peat between this point and the present surface. Although this rate may have varied from time to time, the variations were probably not great, and therefore it can be relied upon to determine the approximate age of the different layers in the peat.

On the basis of the date which has been given to the six foot level in the Wellington Marsh and assuming the correlation of the peat in this marsh with the deposits in the building excavation is valid, tentative dates can be assigned to the various layers at the latter locality. These dates are merely approximate and are not considered exact.

Shell Layer 3	1000 B.C.
Shell Layer 2 (Upper Wattle)	1400 B.C.
Shell Layer 1 (Lower Wattle)	1500 B.C.
Top of the Lower Peat	1700 B.C.
Bottom of the Lower Peat	3000 B.C.

From these figures it appears that the Fishweir was in use about 300 years,

[13] Huntington, E., 1914. *The Climatic Factor Illustrated in Arid America.* Carnegie Inst. Wash. D. C., Pub. 192.

and that the time between the placing of the Upper and Lower Wattles was about 100 years.

RATES OF SEDIMENTATION AND SUBMERGENCE

The dates of the deposits in the building excavation can be used in the discussion of the geology of the site, particularly in estimating the rates of sedimentation and submergence. Interestingly enough the figures obtained, although they are probably not precise, seem to fit in well with many of the observed facts. In this way they offer further proof of the validity of the correlation of the Fishweir deposits with those of Wellington Marsh.

The rate of deposition apparently varied considerably during the time the deposits in the building excavation were laid down. According to Stetson and Parker the grain size in the sediments increased upward,[14] but this is not necessarily indicative of the rate or the amount of deposition. The question of the amount of tidal scour and erosion enters into the picture making the problem complex. Undoubtedly the rate varied considerably within short distances.

The following estimates of this deposition are based upon the tentative dates given to the different layers by means of pollen analysis. It appears that directly above the peat the deposition of the silt was very slow, but above the −15′5.09″ horizon there was a sudden change in conditions resulting in much more rapid sedimentation. This lasted until the time of Shell Layer 1. It was during this same period that Linder, from the study of the diatoms, suggests that the locality was exposed to the influences of the ocean.[15] Between Shell Layer 1 and Shell Layer 2, during the time the Lower Wattle was in use, deposition appears to have been much slower. The diatoms show that during this period the water was relatively warm and the locality was apparently cut off somewhat from marine influences. Above Shell Layer 2 deposition gradually increased upward to Shell Layer 3 and as in the case of the deposits below Shell Layer 1 there are indications from the diatoms of a return of the colder water of the ocean. The rate of deposition of the sediment above this horizon was much slower until eventually plants were again able to get a foot-hold. It appears, therefore, that the periods of more rapid sedimentation, according to these figures, corresponded with the invasion of the colder water of the harbor.

Estimates of the rate of submergence have been based upon the data used for estimating the rates of sedimentation. However this problem is more difficult as many uncertain factors enter into the calculations. The Lower Peat apparently began to form near high tide level. The upper part of this

[14] P. 42. [15] Pp. 75–76.

peat was probably deposited near low tide. The shell layers also appear to have been located at or close to the low tide level. From these assumptions plus a consideration of the compaction of the Lower Peat and the time scale from the pollen analysis, the following tentative conclusions have been drawn.

1. During the formation of the Lower Peat (3000 B.C. to 1700 B.C.) submergence was relatively rapid, somewhat over a foot a century.

2. This was followed by a period (1700 B.C. to 1500 B.C.) which lasted to about the time of Shell Layer 1, when there was little or no submergence.

3. Above this layer the rate of submergence again increased (1500 B.C.–1000 B.C.) to approximately one and one-half feet per century.

4. Finally, after this period and lasting to the present, submergence appears to have been, as a whole, much less rapid.

The position of Shell Layer 3 indicates that sea-level at that time was four to six feet below its present position. This fits in with the observations of the author on marsh deposits on Cape Cod. In the Flume Pond deposit in Falmouth and in a marsh in Sagamore the diatoms indicate that sea level was about six feet below its present stand soon after a well marked pine maximum. The latter has been referred to the Sub-Boreal. This also fits in with the evidence from the Dismal Swamp in Virginia[16] where the diatoms indicate that sea level was about six feet below its present stand on the coast of Virginia at the time of a prominent pine maximum which is apparently of the same age as that on the Cape.

It appears from these studies of submergence and from the evidence of the deposits in the building excavation that sea level changes were most rapid during the times when there is evidence of dry climatic conditions and on the other hand these changes were less during those periods of increased rainfall. This agreement may be purely accidental, but since it is what would be expected, it is therefore very suggestive.

CONCLUSIONS

This study has shown that although there has been no radical change in the forest flora in the Boston area during the last few thousand years, there is evidence that suggests that the Boylston Street Fishweir was built near the end of a dry period similar in character and position to the Sub-Boreal of the European chronology. Whether or not it was warmer or dryer than at

[16] Lewis, I. F. and E. C. Cocke, 1929. "Pollen Analysis of the Dismal Swamp Peat." *Journ. Elisha Mitchell Sci. Soc.*, Vol. 45, No. 1, pp. 37–58.

Cocke, E. C., I. F. Lewis and R. Patrick, 1934. "A Further Study of the Dismal Swamp Peat." *Amer. Journ. Bot.*, Vol. 21, pp. 274–395.

present cannot be definitely determined. The Fishweir was in use, according to tentative figures, about 300 years and was replaced about 100 years after the time it was built. It was finally abandoned about the end of this period of dryness, tentatively dated 1200 B.C. This apparently was a time of increasing cold and storminess, but whether or not this was the reason directly or indirectly for abandoning the structure cannot be determined. Important changes in sea level also appear to have occurred previous to and at the time the Fishweir was in use. The rate of these changes seems to have varied considerably throughout the time recorded by the study.

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CHAPTER 10

MISCELLANEOUS IDENTIFICATIONS AND DISCUSSION

BIRD BONES

A NUMBER of bird bones were found in the Amorphous Layer in the trench. These were submitted to Dr. Glover M. Allen[1] for identification. He writes, "The bird bones are clearly the trunk bones of a large shorebird, which in the lack of more diagnostic parts, I take to be probably a Greater Yellowlegs."

MOLLUSKS

Dr. William Clapp[2] has kindly identified the following mollusks which originated in the building excavation. Unfortunately the provenience of these is unknown.

Mulinia lateralis	*Crepidula plana*
Vitrinella shimeri	*Ilyanassa obsoleta*
Mytilus edulis	*Mya arenaria*
Macoma balthica	*Litorinalla minuta*
Utriculus caliculata	*Anomia suriflix*
Odostomia bisuturalis	*Gemma gemma*
Pryamidella nivea	

Dr. Clapp comments especially upon the presence of *Vitrinella shimeri* which has a distinctly southern distribution and is an indication of a warm water environment.

MARINE BORERS

Marine borers were found in a majority of the stakes from the Fishweir. All that Dr. William Clapp[2] identified were, without question, the remains of *Bankia gouldi*. It seemed strange that no other borer was discovered.

This is the first record of this borer north of Cape Cod. The numbers and large size of the borers indicate that they were probably living under optimum conditions. *Bankia gouldi* inhabits waters which are considerably warmer than those which are now found in Boston Harbor.

[1] Museum of Comparative Zoology, Cambridge, Mass.
[2] Clapp Laboratories, Duxbury, Mass.

PART III

A DISCUSSION OF THE IMPLICATIONS AND SIGNIFICANCE OF THE DATA FROM THE BUILDING EXCAVATION

FREDERICK JOHNSON

INTRODUCTION

THE Fishweir is located in the estuary which forms the mouth of the Charles River. The estuary lies in the Boston Lowland which occupies the central section of eastern Massachusetts. The Lowland ". . . extends from Lynn on the North Shore, to Weymouth, on the South Shore, and includes the Islands in Boston harbor as well as most of Hull. It extends westward up the valley of the Charles River into the Framingham quadrangle and southwestward up the valley of the Neponset River into the Dedham Quadrangle."[1] (Index Map, Fig. 1.)

The Lowland and the surrounding country have seen a long and complicated geological history. The numerous events are interesting and important, but except for the latest developments in the region, they have no direct relationship to the problems involved in the study of the Fishweir. For this reason, nothing but a most general background need be presented.

The area occupied by the Boston Lowland is underlain by relatively weak rocks. These rocks lie between slightly higher uplands in which the crystalline rocks deviate from their usual southwest-northeast trend to curve strongly eastward. In the course of time the less durable of these rocks were eroded to form the lowland. Rocks of intermediate hardness resisted erosion and remained above water to become peninsulas projecting eastward from the mainland, or to form irregularly distributed small islands.[2] The weakest rocks underly the rivers, valleys and bays. Following its original formation, this lowland passed through several major movements of the land and was affected by several changes in sea level until finally, with the initiation of the present shore line cycle, it became submerged beneath the sea.

During the earliest phases of glacial times the Boston Lowland was covered with a complex mantle of till and gravel. Drainage from the hinterland incised stream valleys into this mantle, and the history of the present river valleys was begun. It seems probable that the present river valleys, formed by dissection of the mantle of glacial materials, followed more or less closely the course of the preglacial valleys and so it is rather generally believed that glaciation did not drastically change the ancient topography of this part of New England.

When the Wisconsin ice sheet, the last to invade New England, had disappeared from Massachusetts the end of the Pleistocene epoch was reached.

[1] LaForge, 1923, p. 9.

[2] Johnson, 1925, p. 61. LaForge, 1932., passim.

At some time after the ice had disappeared, the coastal region of northeastern Massachusetts, and the land to the north and east bordering the Gulf of Maine, were submerged beneath the sea. During this submergence much of this area was covered with deposits of marine sediment. Whether the Boston Lowland was also submerged at this time is open to question. There is some possibility that the Boston Lowland was in the vicinity of the hinge of the movement of the earth's crust, and thus, there may have been relatively little change in the relation between the elevation of the Lowland and the level of the sea.

The period during which this submergence to the north and east took place was not of long duration. It was followed by a period during which the land was elevated. The elevation occurred over a much wider area than the previous submergence, and the extension of this area included the Boston Lowland, which rose to a position higher than its present relation to sea level. This emergence exposed the newly formed marine sediments. Subsequent to their exposure, these deposits were dissected and otherwise modified, especially about the heads of tidal inlets. Such was the situation at the beginning of the Recent epoch.

During the Recent epoch the land was subjected to a gradual and progressive submergence, which may have ceased only a few thousand years ago. The question whether this submergence is still going on will be discussed later. This submergence, in "drowning" the coast line, has enlarged the shallow estuaries, such as those at the mouths of the Charles and Mystic Rivers. Coincidental with the submergence, loose material has been washed off the slopes to form flood plains, level meadows and swamps. The enlargement of the estuaries has been accompanied by the growth of peat beds and by the deposition of silt. This study will be concerned with these very late geological events, for, while the peat was forming and the silt accumulating, men built the structure, which we call a Fishweir, in the Charles River estuary.

GENERAL GEOGRAPHY OF THE REGION

GEOGRAPHY OF THE BOSTON LOWLAND

THE coastline of the Boston Lowland forms the shore of Boston Bay. Boston Harbor is a large estuary nearly cut off from the Bay by the peninsulas reaching out from the north and south shores (Index Map, Fig. 1). On both these peninsulas are beaches several miles long. Revere Beach is on the outer shore of the northern peninsula, which is the site of the town of Winthrop. Nantasket Beach forms the outer shore of the Hull peninsula to the south. Some geologists believe that these two peninsulas are mainly made up of drumlins tied to one another and connected to the mainland by beaches and marshes. Between these two peninsulas, and irregularly distributed within the harbor, are a number of islands which protect the inner harbor from all but the most violent storms.

Three small rivers, draining the Lowland, flow into the harbor. The mouths of these rivers are estuaries, and these are responsible for the tortuous shoreline of the harbor. Between the rivers and their estuaries the land lies in the form of irregularly shaped peninsulas projecting from the mainland in a more or less easterly direction. The rivers radiate from the harbor —the Neponset draining the southwesterly section of the Boston Lowland, the Charles, the westerly, and the Mystic, the northwesterly sections. Since these rivers and their valleys were natural routes of communication with the hinterland, it was natural that cities would be built on the peninsulas between them. Greater Boston, located between the Charles and the Neponset, enjoyed the advantages of both these rivers.

The most prominent characteristics of the topography of the Boston peninsula are the remains of hills which the colonists described. Beacon Hill, rising above the waters of Back Bay and the harbor, was formerly topped with three low summits called Pemberton Hill, Beacon Hill and Mount Vernon. Northwest of Beacon Hill was a low rise called Copp's Hill; and Fort Hill, of no great height, lay to the southeast. These hills were connected with the mainland by the "Neck" which was a narrow strip of land and marsh (Fig. 1).

South of Boston proper lay, in colonial times, an expanse of marshland and mud flat, drained by winding creeks, which were part of the estuary of the Charles River. Further to the southeast we still find the hills of Dorchester and the low-lying coast bordering Boston Bay. Inland from this coast, the low areas may be either alluvial plains or swamps, and these are interrupted by rounded hills and slopes of till.

The Boston Peninsula enjoyed other advantages than its favorable location between the rivers. Deep water on the harbor side permitted ocean-going vessels to land their freight and passengers easily. The land upon the slopes of Beacon, Copps, and Fort Hills was suitable for farming and, pasture. There was plenty of fresh-water in the swamps, such as the "Frog Pond" on Boston Common, and wells were easily dug in the gravel. The "Neck," an important feature of the peninsula, was narrow and could be easily fortified; it also provided an easy means of transportation to and from the early town. The road, which was built along this neck and across the marsh into Roxbury very soon after the settlers had become established, was the forerunner of Washington Street, which, even now, is one of Boston's busiest thoroughfares.

EARLY DESCRIPTIONS OF THE BACK BAY, BOSTON NECK, ETC.

The Charles and Mystic Rivers were most important to the colonists as a means of communication with the interior. However these rivers were closed to deep water navigation by oyster banks which were located in their estuaries. These banks must have been large ones in 1634, for William Wood writes of the Mystic, "Ships without either Balast or loading, may float downe this River; otherwise the Oyster-banke would hinder them which crosseth the Channell." Concerning the Charles he says, "Ships of small burden may come up to these two Townes (Cambridge and Watertown), but the Oyster-bankes doe barre out the bigger Ships."[3] In describing the Mystic in 1663, Josselyn writes, "Towards the Southwest in the middle of the Bay is a great Oyster-bank, towards the North-west is a creek; upon the shore is situated the village of Medford, it is a mile and half from Charlestown."[4]

The estuary of the Charles River, forming the western shore of the Boston Peninsula, broadens out into a wide, marshy bay before passing through a relatively narrow mouth into the harbor. This bay together with Fort Point Channel on the eastern shore of Boston proper forms the boundary of the Boston Peninsula (Fig. 1).

Descriptions of the estuary and peninsula are many and they begin very early in the seventeenth century. A few years after 1621, when Miles Standish described Boston Harbor and the Mystic River,[5] Europeans established permanent settlements in the Boston Lowland. In 1634 William Wood wrote, "Boston is two miles Northeast from Roxberry: His situation is very pleasant, being a Peninsula hem'd in on the South-side with the Bay of Roxberry, on the North-side with Charles-river, the Marshes on the back-

[3] Wood, 1634, pp. 41, 42. [4] Josselyn, 1663, p. 127. [5] Winsor, 1880, Vol. 1, p. 63, et seq.

side, being not halfe a quarter mile over; so that a little fencing will secure their cattle from the Woolues."[6] Winsor, noting this description and others, says that Boston was connected with Roxbury by a "long narrow strip of land properly called 'The Neck' which, beginning to narrow just south of Eliot Street, stretched away like a ribbon of varying width to the mainland. Vastly different however, to its present aspect was its condition in those early days when the road which traversed it was well nigh impassable in the spring, when the horses waded knee-deep in water at full tides, when the only timber on the whole peninsula grew upon the Neck, and the marshes on either hand were the favorite hunting-ground of the sportsman."[7]

There are several later references from which something of the nature of the Neck may be deduced. In addition to its being flooded by the "full tides," or Spring Tides (?), there were times when storms washed over the Neck, raising havoc with the city even as late as the middle of the nineteenth century. Perley[8] has assembled several records of such storms and their accompanying high tides, one of which did considerable damage along Northampton Street. This region, southwest of Massachusetts Avenue, was, during early colonial times, part of an extensive marsh (Fig. 1).

Josselyn in 1663[9] mentions the existence of "marsh" northwest of the Neck (Fig. 1) and says, "Up higher (from Boston) in the Charles-River westward is a broad Bay two miles over, into which runs Stony-River and Muddy-River." The marshes and bay were variously named, until finally the region became known as "The Back Bay," the name which is now applied to the district. The extent of the Back Bay has been indicated on numerous early maps, particularly those of the British Admiralty. In searching for reasons for the location and ranges of the many batteries about the Back Bay one is struck with the idea that, although the Bay was composed of flats and marshes, it may have been possible to move across it in order to approach the Neck and the west side of the peninsula. The conventions on the maps also show that probably there were drainage channels or small creeks which would float small boats at the proper tide.

During the latter part of the eighteenth century a dam was built, eventually to become an extension of Beacon Street. This dam was to provide power for a tide mill. The project was not successful because the drop in tide and the physical features of the locality were not suited to the undertaking. The water impounded by the dam created a stinking nuisance, which finally aroused the citizenry, and in 1856 the final filling in of the area was begun.[10] This filled land provided an area over which the city expanded.

[6] Wood, 1634, p. 39. [7] Winsor, 1880, Vol. 1, p. 531. [8] Perley, 1891.
[9] Josselyn, 1663, p. 127. [10] Bruce, 1940.

THE INTERNAL STRUCTURE OF BEACON HILL, THE NECK AND ADJACENT AREAS, A RÉSUMÉ

COPPS, Fort, and Beacon Hills are the most prominent features of the Boston Peninsula. Very little is known about the deposits of Copps and Fort Hill because these were removed before any satisfactory record was made of them. Despite the removal of its three summits, Beacon Hill has survived to a great extent. This hill, and probably the other two, was composed of till. Borings in Beacon Hill report layers containing different percentages of clay, and gravel. The structure of Beacon Hill is puzzling. The details of the layering of the gravels, though inadequately known, have always been interpreted as indicating that the hill is a drumlin. Irving B. Crosby has said that Beacon Hill is an "abnormal drumlin,"[11] but this explanation is not completely satisfactory.

The relationship between an underlying blue clay and the deposits which formed Beacon Hill is not clear. Irving B. Crosby says, "The clay was deposited after the drumlins but this does not fix the age of the clay, as the drumlins might have been formed in an earlier glaciation, and the clay, although younger than the drumlins might still be older than the last glaciation. However, the surface of the clay shows characteristics of stream erosion, the gullies in it have not been cut by glacial erosion."[12] This interpretation, as well as others which have been made, lose much of their weight when the data upon which they are based are appraised.

The hypothesis that the hill is a drumlin can be seriously questioned; in addition, the complicated layering of the deposits has been by no means clearly and completely described. In general, it seems probable that the blue clay on the west or estuary side of the hill was laid down on top of the till, which in places extends some distance beneath it. On the east side of the hill, however, the situation differs in that the beds of various types of sand, together with a bed of yellow clay, and another of sand and gravel, which comprise that section of the hill, rest upon the blue clay. Cross sections showing that the blue clay extends beneath the whole hill from the estuary to the harbor have also been drawn.[13] Until the order and characteristics of these deposits have been clarified, detailed discussion and interpretation seems rather futile.

[11] Crosby, I B., 1934, p. 140.
[12] Crosby, I. B., 1934, p. 153.
[13] Sawtelle, 1931.

The composition of the Neck, which, with the colonial marshes, connected Boston proper with the mainland, is puzzling. According to available borings,[14] the southern end, north of Waltham Street (Fig. 1), is made up of "clay and rocks" and "hard clay." Where it widens out to meet the southern slope of Beacon Hill, i.e. south of Eliot Street, "hard, yellow clay" is recorded. The report "clay and rocks," which is only occasionally found in records of the local deposits and "hard clay," is not well differentiated from the records of blue clay which underlies the Neck. From this type of record it is impossible to do more than guess about the characteristics of the Neck. It may be suggested, however, in view of the mention of rocks, that the Neck may be a tongue of till projecting out from Beacon Hill.[15] This suggestion is not in keeping with several statements in the literature which say that the Neck was built by tidal action. The most striking feature of the Neck is the narrow tongue projecting to the south of Eliot Street. It may properly belong with the whole extension beginning in the neighborhood of Boston Common. This feature, together with the swamps, i.e. the Frog Pond (Fig. 1), and the swamp which once existed between Tremont and Eliot Streets, east of Park Square, are not characteristic of drumlins.

The southern end of the Neck loses itself in a marsh, as is shown on several colonial maps, for example, the Pelham map drawn in 1775.[16] It seems logical to assume that it was this southern section of marshland which was flooded during periods of high water and hampered colonial transportation between Boston and Roxbury. The location of sections of the marsh are recorded in several borings, as well as in Colonial records, and these are responsible for the location of the junction between dry land and the marsh at a point two hundred and fifty feet south of Waltham Street (Fig. 1).

[14] Sawtelle, 1931, and also logs of borings on file in the Boston Society of Civil Engineers, Boston, Massachusetts.

[15] Crosby, W. O., 1903, p. 79. In interpreting the records of borings in other parts of Boston this author noted that a boring recorded "clay and stones." This, he believed to mean "bowlder clay," which in this study is called till. In following such an interpretation of the records the considerable possibility of error is fully realized.

[16] Pelham, 1777.

THE DISTRIBUTION OF MATERIALS IN THE BOSTON BASIN

THE UNDERLYING BLUE CLAY

As has been previously noted, the blue clay is a deposit of clay which is usually fine grained, including a high percentage of almost colloidal material. The clay rarely includes small stones and pebbles which are thought to have been carried over the deposit and dropped by floating ice. W. O. Crosby describes the clay as follows. "It is in the main a very tough, plastic clay, but containing, as do all glacial clays, a large portion of impalpably fine sand or quartz flour. There are, however, occasional thin streaks and layers of true sand. . . ."[17]

The blue clay which underlies the Charles River estuary exhibits several varieties. For example, well logs of borings mention hard clay, medium soft and medium hard blue clay, blue clay and modified drift. In addition to blue clay, a yellow clay is sometimes referred to and note is made that this yellow deposit is simply blue clay which has been oxidized through exposure to the air. Beneath the area in which the Fishweir was found there was a layer of blue clay, described as varying between hard and soft and ranging in thickness between two and eight or more feet. This blue clay lay upon a stratum of yellow clay which varied somewhat in thickness and consistency (Fig. 2). Beneath this yellow clay lay blue clay described as either hard or soft and including, in various areas, silt or sand or other materials.

The blue clay is distributed over much of the Boston Basin but it is a question whether the area is covered by a single deposit. The references to it, which treat it as a single deposit, show a lack of detailed study of the various sections which have been exposed. There is a possibility that the various sections of the clay may have been deposited under different conditions. Thus it is possible that the term blue clay has been applied to several deposits which arose through a succession of geological events in the region.

In general, it appears that the clay is the result of the washing of till and other glacial deposits by water which may have originated from melting glacial ice. W. O. Crosby believes that this clay was deposited in a glacial lake which once occupied the region. He says, "It was laid down in regular horizontal layers, and probably completely filled the basin of Lake Shawmut up to the highest level now reached by the clay, which is about 5 to 10

[17] Crosby, W. O., 1903b, p. 83.

feet above present high tide level." His reason for the assumption that the clay was of fresh water origin is that no fossils had been found in it and also "that similar clay is not being deposited in the harbor at the present time, except perhaps to a limited extent on the eel-grass flats."[18] Some of this blue clay may have been deposited in fresh water but that which underlies the site of the Fishweir certainly was not. The discovery of foraminifera in the clay by Stetson and Parker[19] is definite evidence that at least the upper layer of it was of marine origin. The extent of this layer of marine clay is, of course, unknown but it is hard to believe that it does not cover most of the area of the estuary.

Where the clay does not rest upon bed rock it rests on a deposit which may be till. This foundation ranges between eighty feet and 200 feet below tide level. The characteristics of the till, i.e. whether it is weathered or not, are not well known. According to W. O. Crosby this till is distributed on the sides of ancient valleys which have been cut in the bed rock. He believes that the absence of till in the bottoms of these valleys is evidence that glacial ice "continued to move along these lines after it had become stagnant on the uplands."[20] Deposits, apparently lenticular in shape, of what seems to be till are found interstratified in the blue clay. These beds range from ten to twenty-five feet in thickness and are found, most frequently, near the bottom of the clay. Whether or not the bed of "sand and gravel" west of Exeter Street[21] (Fig. 13) is also till is not clear. This bed may be the one referred to by W. O. Crosby when he mentions "phenomena . . . in the lee of the Beacon Hill drumlin." Crosby postulates that the interbedding of blue clay and till was caused either by slight advances and retreats of the glacial ice while the clay was being deposited or by the ice rafting of glacial detritus.[22] This and the character of the underlying till and bed rock he believes to be proofs of the glacial origin of the clay.

The question of which advance of the ice produced this clay cannot be settled, nor can it be discussed profitably at the present moment. It is possible that the blue clay is the product of the last advance of the ice. It is probable that there are several different beds of blue clay, and possibly these may be correlated with several movements of the ice. Again some clays may have been deposited before the last general advance of the ice and are, therefore, interglacial in origin as was suggested by Brown in 1902.[23] Irving B. Crosby has suggested the possibility that the clay might be older than the last glaciation.[24]

[18] Crosby, W. O., 1903b, pp. 82, 83. [19] P. 42. [20] Crosby, W. O., 1903b, p. 77.
[21] Worcester, 1914, p. 407. [22] Crosby, W. O., 1903b, p. 83.
[23] Brown, 1902, p. 450. [24] Crosby, I. B., 1934, p. 153.

The present surface of the blue clay within a radius of one-half a mile of Boston is found from five feet and probably more above, to some fifty feet below high tide. The general opinions concerning the development of this surface are that at one time it lay about forty feet above sea level. During this time, drainage channels were incised into it and some believe that this surface was oxidized. Following this, the surface was submerged to its present position, a distance of forty feet or more. In the Back Bay the surface of the blue clay may be found from 0.00 Boston City Base to about −40 feet, the deeper portions being the location of presumed channels and depressions cut during previous periods of erosion.

While a detailed study of the topography of the surface of the blue clay in the Back Bay would be of interest, it has no particular bearing on the present problem, except as it bears upon the formation of the Neck and the location of the Fishweir. From the few borings which have been taken on the southern parts of the Neck it appears that, beginning some two hundred and fifty feet south of where Waltham Street crosses the Neck (Fig. 1), the surface of the blue clay is some ten feet below Boston City Base. The clay is covered with silt and marsh and so it may be believed that at one time it was covered with salt water. Whether a channel connecting the Back Bay with the South Bay ever ran on the blue clay in the neighborhood is a question which will be discussed later on.

The Fishweir is located in an area where the surface of the blue clay, lying between approximately −16′ 5″ and −20′ 5″, is relatively flat but gently sloping toward the southwest. This slope leads down to a presumed channel which runs in a general northwesterly direction, i.e. out Dartmouth Street, to the present channel of the Charles River. A depression near the junction of Berkeley and Boylston Streets suggests the existence of another such channel but this has not been traced out.

THE PEAT IN THE BOSTON LOWLAND EXCLUSIVE OF THAT IN THE BUILDING EXCAVATION

The Boston Lowland is dotted with fresh water swamps and, within the range of the tide, salt water marshes line the shores which are protected from the more violent erosive action of the sea. Both fresh water swamps and marine marshes produce peat. Peat varies greatly in thickness and consistency according to the complexity of local conditions. Peat is an accumulation of roots and stems of the flora mixed with the remains of other organisms and silt. Pollen originating in neighboring localities is blown over

swamps and marshes to become imbedded in accumulating deposits of peat. Peat is said to grow because the material of which it is composed accumulates on its surface and adds to its thickness. Through a study of the ecology of the organisms responsible for the accumulation, much can be learned of the environment which obtained during the growth of the peat. Characteristic parts of grasses and sedges may testify to the depth of water which was present over the surface upon which they grew. Further, these grasses and sedges will indicate whether the environment was marine or fresh water. Other organisms substantiate these identifications to varying degrees, depending upon their nature. Through the identification of pollen from successive levels in the peat a knowledge of the evolution of the flora of the region may be gained.

In this study the term *marsh* is applied to areas where peat has accumulated in a marine environment. Such marshes may be buried, i.e. they are now extinct, or they may be flourishing today. The term *swamp* is used here to denote a fresh water environment. In the Boston Lowland some marshes have succeeded swamps. In these places there is usually a continuous deposit of peat. The identification of organisms, particularly grasses and sedges, has shown that the lower sections of the peat originated in fresh water and that the upper sections grew in a marine environment.[25]

The marshes in the estuaries of the Saugus, Mystic and Neponset Rivers in the Boston Lowland and a few marshes just outside the boundary of this region have been partially investigated and at least one attempt has been made to synthesize the results.[26] In general it has been found that the lower sections of the seaward portions of these marshes now lie below tide level. The grasses identified in the lower levels in the peat were those which lived near the range of high tide. These identifications demonstrate that the peat was deposited during a period when sea level was lower than at present and that the deposit grew upward as sea level rose. The marshes still support a flourishing vegetation. While some work has been done on the development of particular marshes,[27] attempts at detailed comparison and correlation have been, of necessity, restricted to veiled suggestions. It is not possible to date these marshes very satisfactorily if at all, nor to say which marsh had the earliest beginning. In addition, little can be said about the climatic conditions which obtained while the marshes developed. Such problems await investigation of the pollen, diatoms and other organisms which are present, and the establishment of a geo-chronological time scale.

[25] Cf. Chapman, 1938, 1940a, 1940b.

[26] Johnson, 1925, Chapter XVI.

[27] Johnson, 1925, Chapman, 1938, 1940a, 1940b, Knight, 1934, etc.

THE PEAT IN THE CHARLES RIVER ESTUARY AND IMMEDIATE VICINITY

The distribution, in the estuary, of peat beds can only be determined from the records of borings, because the peat has rarely been exposed. Under these circumstances it is impossible to identify the peat; we do not know whether it originated in a marine or fresh water environment. The only clew is found in the building excavation where two layers of peat were exposed. The Upper Peat was formed in salt water and the Lower Peat was in part formed in fresh or brackish and in part in salt water.

The discoveries in the building excavation may be used as the basis for assuming that the peat in the estuary, as recorded by the borings, may be identified as Upper Peat if it lies above −10′. Peat resting upon blue clay at a depth of more than −10′ may be included with the Lower Peat. In one location, discussed below, a peat bed twenty-seven and one-half feet thick was encountered. It is here assumed that this bed is composed of the two layers which are superimposed one upon the other.

The deposits of peat in the estuary are difficult to trace, for the logs of the borings are not always precise. It seems that frequently peat is included under general terms "silt," "muck," or even "dock mud." In this discussion, unless specific mention of peat is made, the records of borings are treated with due caution.

The Lower Peat

The Lower Peat occurs in large beds which rest upon the blue clay. These beds are clearly identifiable in locations where they are thin, i.e., from one to two or three feet thick, and where they lie deeper than −10′. The Lower Peat is always covered with a deposit of silt except in localities where the Upper Peat is, theoretically, superimposed upon it. Two records which may be interpreted as such superimposition have been found. Shimer[28] notes that at Church Street a tree stump was found at −15′ and that it was taken from near the top of a peat bed. The bottom of this bed was located at −33′. The other record, from the same source, is located, "At the Public Garden side of Charles and Boylston Streets." Here the top of the bed is located approximately six inches above Boston City Base and the bottom is at −27′.

From what records we can find, the approximate distribution of the Lower Peat has been indicated by the stippling on Figure 1. A large area

[28] Shimer, 1918, p. 447. The figures for the depths have been converted to depths below Boston City Base, the plane of reference used in this report.

occupying the central part of the estuary has been delimited but it seems probable that the peat does not completely cover the whole area. Rather, there are grounds for the assumption that the area included several marshes which may have been separated by drainage channels or even small bays. The principle deposit was an irregularly shaped marsh, the eastern margin of which was near Charles Street. The westernmost edge lay in the vicinity of Gloucester Street (Fig. 1). Further extension to the west is suggested by a boring on Beacon Street, west of Massachusetts Avenue. The possibility that the bed extended to the east and north is suggested by one or two borings, particularly between Cambridge and Fruit Streets. All the boundaries cannot be ascertained because of the lack of data. One boring on Beacon Street east of Clarendon Street records the Lower Peat, but as a whole the northern edge of the bed cannot even be suggested.

A second, smaller bed possibly existed near the corner of Berkeley and Tremont Streets. There is only one boring in this vicinity which reports peat and so the extent of the bed is unknown. It has been drawn on Figure 1 in a size which may be seen easily.

Borings in Fort Point Channel and a record from the Commonwealth Flats in South Boston,[29] to the east of Boston proper, record the existence of beds which may well be Lower Peat. The possible extent of this bed has been indicated by the stippling in Figure 1, but obviously it remains to be corrected by further investigations. A possible record of Lower Peat is found in one boring among several which were made in Mill Cove.

The Upper Peat

The distribution of the Upper Peat can be determined from the well logs of the borings in a manner similar to that employed for the Lower Peat. A wealth of additional data is supplied by descriptions, charts and maps which were made by the colonists. The Upper Peat is identified as those beds lying above −10′. The surface of the bed is usually close to 0.00. In addition, this surface has been covered with artificial fill. In locations where the Upper Peat is superimposed on the Lower Peat, it is practically certain that the upper layer is simply a continuation of the upward growth of the lower and hence any division is arbitrary and may prove to be spurious.

About the shores of the estuary, the Upper Peat appears to be three or more feet deep. This is considered as a separate layer of peat because available data show no connection between its lower sections and the Lower Peat. It is wholly within the realm of possibility, however, that proper and ade-

[29] Shimer, 1918, p. 447.

quate studies of these deposits will show a continuity of development from the lowest sections of the Lower Peat to the surface of the Upper Peat, regardless of the horizontal distribution and the vertical depths of the deposits.

As shown in Figure 1, the Upper Peat is found around the shores of the estuary. The boundaries of this peat correspond to the limits of Colonial marshes. A boring near the head of the cove, now under Cambridge and Fruit Streets, records seven feet of peat and mud resting upon a thin layer of sand which in turn is underlain by blue clay.

Further to the south two areas of marsh projecting from the shore line have been noted by early chart makers. It seems possible that fresh water, draining from the swamp, now called the Frog Pond, may have formed a brook which separated these two areas of marshland. The records of a few borings in this region suggest that the more northerly marsh developed on the surface of a layer of sand and gravel and that the peat of the southerly marsh was deposited upon a stratum of silt.

The long strip of marsh running along the shore between Tremont and Washington Streets was reported by Colonial surveyors. Borings in this vicinity report areas of blue clay beneath this marsh but there are a few references to underlying silt.

The boundaries of the Upper Peat in the western and southern sections of the estuary are located principally from Colonial surveys. Very few borings have been made in this area but most of these few records testify to its presence. Moreover, there are indications that here peat of varying thickness developed on the surface of the silt. The presence of peat to the south of the end of the Neck was noted by Colonial writers and it also was reported by a few borings. In this section the peat rests upon silt.

On the eastern side of the Neck, and extending to the north, there was a narrow strip of colonial marsh. Beneath the peat of this marsh the borings record clay in the southern sections, while silt has been reported to the north. Other marshes have been reported about the eastern shores of the peninsula. The largest of these, in Mill Cove, was, before it was modified by Colonial millers, cut up by several drainage channels. This marsh seems to have been deposited upon silt.

It seems strange that there are no records of marshes in the central sections of the estuary. Conventions on Colonial charts outline what seem to be drainage channels in this area but there is no record of whether the channels ran through marshes or through mud flats. Close scrutiny of the conventions leaves the impression that they represent the latter. Two deposits of Upper Peat are recorded by borings and excavations in the center of the estuary.

One deposit covers the building excavation. The second is noted in a boring made just east of Clarendon Street on Beacon Street. No record of the boundaries of these peat deposits exists and so the areas have been drawn of a size which is easily identified in Figure 1.

Several boggy areas, most of which were probably swamps, were to be found on the slopes of Beacon Hill. The largest one has been named the Frog Pond and, though modified to an artificial pond, is still in existence. Another bog existed between Eliot and Boylston Streets.[30] Tremont Street apparently runs across the center of this bog. It seems possible, after a study of the contours of Boston proper, that the heads of some of the coves on the eastern shore of the peninsula were also of fresh water origin, for they were probably above the range of high tide. However, the land has been modified to such an extent by the builders of the city that such evidence is far from convincing.

THE SILT IN THE BOSTON LOWLAND

The estuaries of the region are all more or less choked with silt. No comprehensive study of these deposits has been made but there is available some data dealing with the silt in Boston Harbor and, more important in view of the present study, in the Charles River estuary. From the records of the borings in this area there is a suggestion of the possibility that several varieties of silt are to be found in different sections of the estuary. However, the descriptions of the various terms are not precise, consequently deposits referred to as muck, mud, or dock mud cannot be differentiated one from the other. It is necessary to ignore this difficulty and to assume that the silt from the building excavation is typical of the whole deposit.

As might be expected, the silt is thinnest near the sloping shores of the estuary and it is deepest near the center. A perusal of the borings shows that the depths range from about one foot to twenty-five feet or more. The reason for this lies first in the fact that essentially, the underlying surface, made up of blue clay, lenses of sand and gravel, and peat beds, is shaped like a large basin. However, the bottom of this basin is cut by drainage channels and interrupted by pockets and hummocks, so that in detail it appears to be rather uneven.

The present surface of the silt in the estuary has a relief of several feet. On the average this surface is located close to Boston City Base. Lacking a detailed study of the surface, it seems likely that the differences in level of the surface are due to drainage channels, pockets and pools, such as may be found on any tidal mud flat. Colonial observation substantiates the testi-

[30] Shurtleff, 1871, pp. 411–412. Courtesy of James L. Bruce.

mony of the borings that much of the estuary was laid bare by the tide.

In describing the silt, W. O. Crosby writes, "The silt is an entirely loose and uncompacted deposit, which is easily moved or drifted about, like sand on a beach, by the action of the current . . . That the silt is very sensitive to variations in the force of the currents is shown by the fact that in a more sheltered area, like the angle between the Charles and Mystic Rivers, off the Navy Yard, it attains a much greater thickness, commonly 10 to 15 feet, with a maximum of 25 feet."[31] This description must apply to uncompacted silt beneath the waters of the harbor or rivers. It is certain that the silt beneath the estuary was once soft and that its present putty-like consistency is due to compaction and the removal of the water.

Stetson[32] has shown conclusively that the silt is of marine origin, a probability suggested by W. O. Crosby.[33] Such silt is brought in by flooding tides and dropped either in localities where the current diminishes or during periods of slack water. In an estuary such as that of the Charles, deposition may be rapid in one place and slow in another. Some slight change in current conditions, as for instance the effects of a single storm, might completely reverse the situation. Under these conditions no valid rate of deposition can be determined and the time required for the accumulation of the deposit cannot be estimated.

[31] Crosby, 1903b, pp. 86–87.
[32] P. 44.
[33] Crosby, 1903b, p. 88.

A DISCUSSION OF THE DEVELOPMENT OF THE DEPOSITS IN THE BUILDING EXCAVATION AND THE IMMEDIATE VICINITY

THE BLUE CLAY AND THE UNDERLYING DEPOSITS

FURTHER detailed discussion of the deposits of clay which underly the site of the Fishweir contributes little or nothing to the solution of the present problem. The significant data may be summarized. At least the upper layers of the blue clay were laid down in salt water and the presence of foraminifera is evidence that the water may have been deep, certainly the surface was not in the intertidal zone but probably some distance below the limits of low tide. Following the deposition, during a period of lower sea level, some of the clay may have been oxidized by exposure to the air. Regardless of whether this took place or not, at least some sections of the original surface of the clay were eroded by running water to the surface upon which the Lower Peat developed. This surface is irregular but beneath the Fishweir it was flat, sloping downward from about −16′ 5″ in the north and east to about −20′ 5″ in the southwest.

THE LOWER PEAT

The Lower Peat has been described as it was uncovered during the excavation of the Fishweir. It extended without interruption over all of the building excavation. The Amorphous Layer of this bed of peat was without question laid down upon the surface of the blue clay. Also it was deposited in a fresh water environment which was subject to inundations of brackish water. The peat which developed upon the Amorphous Layer, the Upper Layer of the Lower Peat, was deposited in water which became increasingly more saline. The surface of this Upper Layer developed in an environment which was virtually marine.

The surface of the Lower Peat was practically flat, being interrupted only by low hummocks and shallow depressions. In the northern and eastern parts of the building excavation the surface lay at −15′ 8.9″ and pitched downward to −18′ 10.56″ in the southern and western sections (Fig. 5).

The distribution of the Lower Peat in the estuary has already been noted. The peat beds which were reported during the excavation of the Boylston Street subway are of particular interest because of their proximity to the

building excavation. In general the area between Charles and Dartmouth Streets was covered with peat (Fig. 13). However there were restricted areas of various sizes where no peat grew. One of these is located to the southeast of the building excavation and this was the site where the Fishweir stakes were found in 1913. The western edge of this spot, lay about one hundred and fifty feet east of Clarendon Street. This marks the beginning of a peat bed the western edge of which lay under Dartmouth Street (Fig. 13). At the eastern edge of the bed, i.e. under Clarendon Street, its surface was slightly deeper than −18′ and it pitched downward toward Dartmouth Street where the surface was located at −20′. The connection between the peat in the building and subway excavations is assumed. The edge, as recorded in the subway excavation, is not found in the building excavation and so it is assumed that it runs in a northeasterly direction. The eastern edge of the bare spot beneath Boylston Street, in which the first Fishweir stakes were found, cannot be identified exactly. However peat has been recorded in various places as far east as Stuart Street (Fig. 1). This meagre data suggests the possibility of a pool or drainage channel in the peat, such being the site of the section of the Fishweir which was discovered in 1913. Such an assumption is difficult to support, however, for the contours of the peat and the blue clay can hardly be interpreted in this manner.

If the close relationship between the peat in the building and subway excavations may be accepted, an area which was first swamp and then marshland which measured at least one thousand feet east and west may be described. The north-south dimensions of the area are impossible to determine because of the lack of data.

Another bed of peat, lying under the region near the corner of Exeter and Boylston Streets, appears in the records of the Boylston Street subway excavation (Fig. 13). A third record is mentioned by Shimer.[34] It seems more than possible that these two records refer to the extension of a single bed. In these two places the peat was reported at eighteen and fifteen and one half feet below low tide.[35] Because of the similarity in depth it seems reasonable to assume that these two beds were laid down at the same time the beds beneath the Fishweir were developing. The only possible exception to this may appear in the deposition of the sand and gravel which underlies the Exeter Street bed. The peat, lying directly upon the surface of the blue clay, may have developed during a period when the sand and gravel was being deposited. If this is the case, the beds beneath Exeter Street are

[34] Shimer, 1918, pp. 444–445.

[35] Mean Low Tide is probably that recorded at the U. S. Navy Yard in Charlestown. This datum plane is 8.8″ above Boston City Base (Fig. 2).

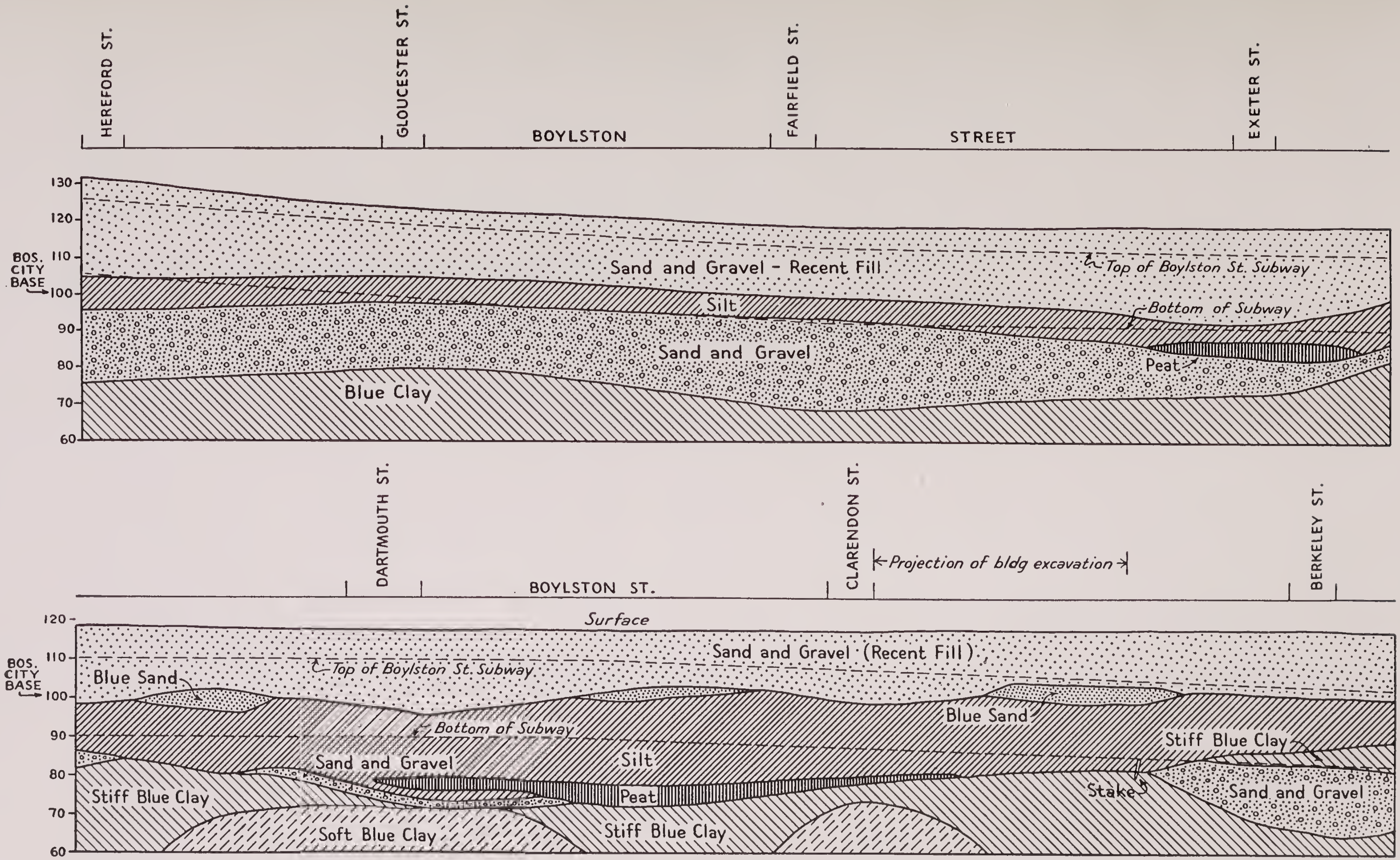


FIG. 13. Cross section of deposits under Boylston Street from Berkeley Street on the east to Hereford Street on the west. Adapted from plans supplied by the Boston Transit Commission.

younger and perhaps different from the beds beneath the Fishweir. Without further data no hypothesis may be upheld. It seems likely, however, that the first assumption is more reasonable.

Easterly extensions of the peat bed are not as clear. Shimer's report of peat under Church Street and under the corner of Charles and Boylston Streets have already been mentioned. Because the conditions described are quite different from those found in the building excavation, one can only speculate upon the possibility of the relationship between these thick beds and the Lower Peat in the building excavation. However, the possibility that the lower strata of these beds may be correlated with the Lower Peat should not be overlooked.

One puzzling characteristic of the beds of Lower Peat is their slope. Since similar present day beds are level, it seems apropos to offer what little data could be found relative to sloping beds. Although the results are meagre, for, as far as could be learned, the question has not been thoroughly investigated, it is profitable to mention a number of aspects which have appeared in this study and which appear to be worthy of further investigation.

It has been stated that probably the surface of the blue clay was eroded to the slopes which have been mentioned. Following this process the slope lay at the proper level long enough for the Amorphous Layer of the Lower Peat to accumulate in fresh or brackish water. Finally the slope was submerged and the Upper Layer grew up in an environment which became marine.

Because of the nature of the environment in which the Amorphous Layer grew, it seems reasonable to believe that the Layer developed at a level somewhere between Mean High Tide and the level reached by the Spring Tides. Assuming, as seems reasonable, that the peat bed exhibited the same characteristics throughout its extent, the difference in level of from three to five feet, being much greater than the difference between the levels of Mean High Tide and Spring Tide, prevents the assumption that it was all formed at one time. The Upper Layer, which finally became a marine deposit, was superimposed on and parallel to the Amorphous Layer. It seems probable that both these layers developed on a slope at a time when sea level was rising.

Since no discussion of the question of how such peat beds are formed on a slope was found in the literature, several marshes within thirty miles of Boston were investigated. It was found that the surfaces of these were practically level, especially in zones whose relation to sea level was similar to the probable former location of the Lower Peat. Areas which were not level and having a grade comparable to that of the Lower Peat were re-

stricted to a zone not more than fifty feet wide along the borders of drainage channels. More rarely, very slight grades were noted along the border between the marsh and the upland but these were not comparable to the location of the Lower Peat. This survey supplied no answer to the question.

It is impossible to make any satisfactory estimate of the amount of compression of the peat.[36] It seems reasonably certain, however, that differential compression cannot be suggested as a reason for the slope. The thickness of the bed is reasonably consistent throughout and it may be assumed that the compression of the peat did not affect the angle of its surface.

Purely as an hypothesis, it may be proposed that possibly the Lower Peat developed "up" the slope as the area was slowly submerged. A band of peat developed upon the submerged Amorphous Layer in the zone between the level of Mean High Tide and Spring Tide. This band ran parallel to the shore and, in the vicinity of the building excavation, its borders ran north and south. It may have first appeared near Dartmouth Street. As sea level slowly rose the band moved to the east through a process of attrition along its eastern margin. Growth in the submerged portion would have been stopped by the flooding of the tide and consequent increasing salinity of the water. Through the eastward growth of this band up the slope, the area finally became covered with the Upper Layer. Such an explanation appears at the moment to be naive and perhaps lacking in foundation. If data can be presented to add to or vitiate the suggestion so much the better.

A further complication in the formation of the peat may be found along the western edge. One hundred and seventy-five feet of this western section of the peat layer accumulated upon a lens of sand and gravel and upon a layer of silt. This situation may have come about through developments which began with the modification of the surface of the blue clay and which were continued through the vagaries of changes which mark the evolution of a surface of an estuary of this sort. Beneath Dartmouth Street and extending some distance toward Clarendon Street, the surface of the blue clay

[36] Knox, pp. 119–120, has had the courage to estimate the amount of the compression of the Lower Peat. This estimate, however, is far from trustworthy. As a point of reference he uses the determinations made by Douglas Johnson and others on peat bogs existing under somewhat different circumstances. Also it seems probable that the peats studied were of different character than the Lower Peat. That the pollen profiles are an indication that the estimated compression is approximately correct is deceptive. The lamentably insufficient knowledge of the character of pollen profiles from this area makes it impossible to know whether those obtained are typical or even complete. Consequently the basis for the "matching" of the pollen profiles of the Fishweir and the Wellington Marsh is extremely hypothetical and the resultant figures for compression cannot be used here. Knox has also pointed out the tentative character of this information.

dips downward (Fig. 13). This, probably, is the remains of an old drainage channel. On the bottom and west side of this channel a layer of sand and gravel some two feet thick were deposited. Following the development of this deposit some eighteen inches to two feet of silt were deposited and then a tongue of peat grew up upon this. Subsequent to the growth of the peat, silt was again deposited and this silt covers all previous deposits.

Knox has proposed the interesting suggestion that a sedge mat grounded on the slope.[37] Without denying this as a possibility, it may be pointed out that the Amorphous Layer was probably an autochthonous deposit and probably could not have been a sedge mat. The Upper Layer was an allochtonous deposit and it may have been a sedge mat which grounded upon the surface of the Amorphous Layer.

It remains to summarize the scanty data dealing with the Lower Peat. In the building excavation, the Lower Peat was deposited on a slope which now lies at $-15' \ 8.9''$ in the eastern end and extends downward probably to $-20'$ under Dartmouth Street. Further west, areas of marsh developed at depths which were intermediate between these two extremes. To the east, an area of marsh lies even deeper than the Dartmouth Street area but it was favored with a continuous development, so that sections of it may correspond with the Lower Peat. The general picture of the section of the Back Bay within the stippled area on the map (Fig. 1) is that of a region dotted with areas of marsh connected by mud flats or separated by drainage channels. As sea level changed, the conformation of these marshes changed. It is certain that eventually they were all submerged, except for a few areas, such as that between Church and Charles Streets, in which the upward growth of the marsh kept pace with the rise in sea level.

In developing an estimate of the amount of submergence, or rise in sea level, which has taken place since the peat began to form, a number of things should be kept in mind. In the first place it is obvious that peat began to accumulate in some places before it appeared in others. Thus we have Shimer's estimate of submergence, based upon measurements at Church Street. If the lowest layers of the bed were similar to the Amorphous Layer in the building excavation they were formed at high tide level and above, so there has been a submergence of about forty-three feet. Under Dartmouth Street the peat did not begin to form until there had been a general submergence of some thirteen feet so that, since its deposition, there has been a submergence of the bottom of the estuary of about thirty feet. Beneath the building excavation there has been even less submergence since deposition, that is, some twenty-nine feet since the western parts of the

[37] P. 118.

deposit accumulated and about twenty-six since the eastern deposits were laid down. The latter figure is of particular interest because it is calculated from the point which marks Level A (Fig. 5) which is the level of the bottom of the Bay upon which the Fishweir was constructed. This brings up the question of when the Fishweir stakes were driven. Were they driven when this level, that of the highest areas of the surface of the Lower Peat in the building excavation, was reposing at Mean High Tide? Were they driven after a certain amount of submergence had taken place, so that the surface of the peat lay in the inter-tidal zone? Although these questions are of prime importance it seems wise to defer attempts at answering them until further data on the deposits has been presented.

THE SILT

Before the Fishweir was constructed fine silt had accumulated to a depth of about three feet in the western sections of the building excavation. During this process of deposition, conditions were favorable for the development of relatively few oysters and mollusks. The oysters developed upwards as the silt accumulated, the shells of these mollusks were scattered, vertically and horizontally, through it.

When the Fishweir was constructed on the level which is now at $-15'$ $8.9''$, called Level A in Figure 5, we know that the bottom was covered with water which was clear enough and deep enough to support oysters and barnacles on the peat and stakes. Thus, while the water probably carried a considerable load of silt, this load could not have been abnormally heavy and deposition took place slowly enough to permit the growth of these species. The relative scarcity of shells, in relation to the number in higher deposits, might suggest that deposition was relatively rapid but there may well have been many other conditions which prevented the mollusks and other organisms from becoming numerous. In addition to the mollusks the presence of barnacles, *Balanus eburneus*, on the stakes suggests that the weir was constructed when the peat had been submerged far enough so that it was not laid bare at low tide.

As the surface of the silt rose above Level A it was accompanied by some activity on the part of the builders of the Fishweir. More stakes were driven and, eventually, when the surface reached the level of the Lower Wattle, Shell Layer 1 developed.

The presence of Shell Layer 1 raises the question of how the silt was deposited, not only among the stakes of the Fishweir but in the whole estuary. The shell layer appears to be the product of some agent which sorted the silt in a different way from that which produced the underlying homogeneous

stratum. One interpretation of this situation is that the silt continued to be deposited at a constant rate and that the Lower Wattle acted as a barrier to slow down the current, thus allowing the coarser sediment to settle out. This interpretation may be satisfactory, especially for this rather elusive layer. However, it is not convincing, for it makes no provision for the presence of the broken shells which were included in the layers or for the groups of mollusks which had died in their natural position.

A second interpretation is that the layer represents a mud flat level which was exposed for a time. During such a time the currents in the weir may have removed the finer particles of silt from the surface leaving behind the coarser material. Furthermore, the shells of the mollusks could have been washed out of the silt and those of the barnacles could have dropped down upon such a surface. Rather elusive and tentative data supporting this idea are observations on mollusks which had died in their natural position. Groups of these were found just below the layer, suggesting that open water was formerly to be found just above Shell Layer 1. W. O. Crosby has made a comment which is of interest in this connection. "The silt, as now distributed, is in part distinctly or highly fossiliferous, and in part free or comparatively free from shells . . . Obviously, the most if not all the shells are too heavy to be transported by the tidal currents, and hence where the silt is suffering erosion the shells are left behind, gradually forming a residuary accumulation or layer, which must tend to protect the silt from further erosion, and the material which has been swept away is deposited in some more tranquil spot free from shells. Hence the absence of shells may be regarded as an indication of transportation from the point where the material was originally deposited; and it is a safe conclusion that the erosion would have been much more extensive than it has been, but for the shells."[38]

The selection of one of these interpretations for Shell Layer 1 can be at best tentative. In view of the location and arrangement of the mollusks, even though they are rare, it seems that the former existence of a mud flat may be postulated. Such a postulation does not interfere with the development of the Fishweir, for the silt could have accumulated in the wattling below the layer and the concentration of wattling on this level may well represent brush which had been put in above the layer, only to settle down upon it. In view of the evasive character of Shell Layer 1 and the Lower Wattle in the western sections of the building excavation, it must be further assumed that while the mud flat existed in the east, silt was still being deposited, though more slowly perhaps, in the west.

[38] Crosby, W. O., 1903b, p. 88.

If Shell Layer 1 does represent an exposed mud flat, it will be asked what became of the process of silting which had been going on in the estuary? In answer to this it may be pointed out that in an estuary of this kind the bottom is never stable and that very often silt may be deposited in one section while the bottom in another section is static or even being eroded away. The description of an oyster taken from a place just below the Lower Wattle shows how sudden variations in conditions can affect such a location. Nelson notes that, "The oyster died suddenly from deposition of rather coarse material, sand, gravel or broken shells with very little mud. It was not subsequently uncovered until excavated. The most probable cause of death was a heavy storm in the fall toward the close of the growing season. . . . Considerable loose material must have been deposited at the time of death."[39]

Shell Layer 1 and the Lower Wattle were eventually covered with silt. The absence of *Urosalpinx* from the assemblage of mollusks in this layer suggests the possibility that the silt was soft.[40] The accumulation of this silt was probably fairly rapid, so preventing the survival of the majority of mollusks. On the other hand, oysters were able to live but the character of their shells is an indication that the rate of deposition was rapid. The silt, which was homogeneous, accumulated to a depth of about two feet, i.e. from a level now reposing at $-14' \ 1.4''$ to one at $-12' \ 10.9''$ and then, suddenly, Shell Layer 2 was developed.

This shell layer was much more plainly marked than the previous one, and the possibility that this was an exposed mud flat seems much greater. In spite of the fact that the layer was difficult to identify in spots, it maybe said with some certainty that it covered the whole of the building excavation. Furthermore, large areas inhabited by several species of mollusks appeared. The mollusks lay in their natural position, just below the shell layer, in a manner which is similar to that which may be observed while digging in any present day clam flat on the New England coast. In addition, this layer included larger pebbles and a greater variety of single valves and broken shells than did Shell Layer 1. If the interpretation is correct, the mud flat represented by Shell Layer 2 was more extensive and lasted a longer time than did the mud flat of Shell Layer 1.

Following the development of Shell Layer 2, the accumulation of silt commenced in this region once again. The next six to eight feet of silt was slightly coarser than that which had been deposited between the shell layers and upon the peat. Also during, or perhaps just previous to, the dep-

[39] P. 53. [40] P. 61.

osition of this silt the oyster bed saw its greatest growth, both horizontally and vertically. The rate of deposition of this layer of silt could not have been faster than could be tolerated by the oysters but it seems to have been too rapid to permit various other species of mollusks to grow in any appreciable quantity. The rate of accumulation was fast enough to have some affect on the shape of the oysters, as has been mentioned by Nelson.

Further deposition of the silt was not interrupted until Shell Layer 3 developed. This layer was similar in its physical characteristics to Shell Layer 2 and, if anything, it was more plainly marked. On the basis of the postulation made regarding these shell layers, this layer was a mud flat level which developed under even more favorable circumstances than the previous ones. Shell Layer 3 differed in that it lay at an angle, whereas the other layers were practically level. There appear at least two possible interpretations of this slope. One is that a sloping mud flat developed on the side of a shallow drainage channel. A second may be that the silt accumulated to the level now reposing at $-4' \, 6''$ or above and then, due to developments elsewhere, changes in the drainage system in the estuary were affected and the level of the silt was eroded away to this gentle slope.

Once again the process of deposition commenced and Shell Layer 3 was covered with some four to six feet of silt and the surface of the silt finally reached a level about fourteen inches below Mean Low Water, as recorded at the United States Navy Yard in Charlestown. The development on top of this of some six inches of peat raises the level of this section of the estuary to 0.00 Boston City Base. If there was no difference between tide level in Boston Harbor and in the estuary in Colonial times, it seems that the peat was submerged some 8.8 inches at low tide, except during the long tides which come with the new moon.

Although the surface of the silt deposit was covered by the Upper Peat in the area of the building excavation it was, in the estuary as a whole, usually bare. From what little data that has been assembled, it seems that this surface lay at or near 0.00 Boston City Base, or some eight inches below present Mean Low Water. The cross section through the Boylston Street Subway excavation extending west from Berkeley Street to Hereford Street (Fig. 13) exhibits a rather regular and gently undulating surface with a relief of about five feet. The tops of the rises are about three hundred feet apart. The three rises between Berkeley Street and a point one hundred and fifty feet west of Dartmouth Street are capped with a deposit of "Blue Sand" which, unfortunately, is not described in further detail. The fourth rise, the peak of which appears just east of Gloucester Street, is the highest of all and is composed entirely of silt.

CHANGES IN SEA LEVEL AND THE CHARLES RIVER ESTUARY

THROUGHOUT the foregoing discussions random references have been made to the submergence of the land or the rise in sea level which has taken place during the geologically recent history of the Charles River estuary and, more particularly, since the Fishweir was constructed. It remains to gather these references together in a summary which will make the sequence of events more clear and which will make possible a tentative description of the changes in topography which took place. In the latter case general considerations dealing with the Boston Basin as a whole may be omitted so that space may be reserved for events which are relevant only to the Fishweir.

At this stage in the discussion the fact that submergence[41] has taken place is obvious. The Lower Peat in the building excavation, regardless of whether it was formed at low tide, high tide or above these levels, was certainly deposited when Low Tide level was below its present relation to the land. The evidence of the diatoms, while perhaps more tenuous, is still corroboratory, for it is unlikely, if not impossible, that the aggregations of species at the different levels could have accumulated in the way they did under the present relation between land and sea. The evidence of the mollusks and other organisms is not as definitive because of the peculiar ability of these organisms to adapt themselves to varying depths of water. On the whole, however, these organisms, suggest that there has been a rise in sea level. Former evidence adduced by Shimer[42] is likewise suggestive and, even though the figures and some of the arguments he offers may not be in complete agreement with those developed here, the conclusion that there has been a relative rise in sea level is altogether sound.

Various estimates of the amount of submergence of the Charles River estuary have appeared[43] and the more recent ones have been based on the figures given by Shimer.[44] Most authors have based their estimates upon Shimer's discussion of the Fishweir and the associated beds of silt, although

[41] The writer follows local custom and uses "submergence" for relative rise of water with respect to land and "emergence" for relative fall. There is no implication, in this usage, that the land moved relative to a static sea level or that sea level moved relative to a stable land level.

[42] Shimer, 1918, pp. 457, 462.

[43] Worcester, 1914, p. 405; Shimer, 1918, pp. 457–462.

[44] For example: Antevs, 1928a, p. 93; Hörner, 1929, pp. 140, 141.

some have discussed the location of the peat. The deep peat beds lying under Fairfield, Exeter, Church and Charles Streets, reported by Shimer,[45] are of considerable significance. Shimer assumed that the peat was formed at the level of high tide and concluded that there had been a submergence of at least forty-three feet. The flaw in this assumption was recognized: the identity of the peat was unknown. If it was fresh water peat, it was formed above high tide and thus the submergence would have been greater. It is likewise possible that the peat was formed in the intertidal zone or even at the level of low tide and so the submergence would amount to a minimum of about thirty-three feet. In view of this it should be pointed out that the submergence calculated at the building excavation is about half of this figure. Thus, the principle and really important point in this discussion is that submergence had been going on in the region for some time before the Fishweir was built. The present lack of evidence prevents further measurement of the total submergence which took place and so it is impossible to say whether the figures given represent the maximum changes in the relative position of sea level during geologically recent times or whether the relative change in sea level has been more than the estimated thirty-three to forty-three feet.

The suggestion of such a submergence is tempting but the recognition of the fact that the measurements come from but a few places in a relatively restricted area of the estuary prevents one from being lured into offering an opinion regarding the topography of the region at a time when the blue clay was, theoretically, exposed. If the data were more precise it would be possible, from a study of the contours of the blue clay, to trace, in more detail than has yet been done, a series of drainage channels, which had been incised in the surface of the blue clay. (One of these, the channel running under Dartmouth Street, has been tentatively mentioned.) In addition, the existence of low islands of blue clay, possibly exposed at low, if not high tide, might be suggested. Further data might corroborate and enlarge upon the existing suggestions[46] that the channel of the Charles River was much more restricted than it is at present; that the Back Bay, as we have been describing it, did not exist; and, that the Neck was not really a neck at all but that Beacon Hill was the end of a wide and respectable peninsula. In spite of these intriguing possibilities, it is necessary to think of them only as a general background for the later picture.

The excavation of the Fishweir, and other data from the building excavation, provides a certain amount of information about the subsidence of the

[45] Shimer, 1918, pp. 447, 457.

[46] Crosby, W. O., 1903a, and other papers.

region. Before producing the figures, it is well to discuss the possible differences in tide level between the site of the Fishweir and the United States Navy Yard in Charlestown, where the planes of reference used here were established. The question of the range of the mean rise and fall of the tide in the estuary throughout its history, may never be settled. With the changes in topography brought about by submergence and deposition, there must have been times when there was a certain lag, and the rise and fall of the tide must have been a few inches less than it was before the Craigie dam was built. There is no way at present of determining this, and it is assumed that the differences were not sufficient to destroy the validity of the discussion. As evidence supporting this assumption it may be added that in 1903, "The Charles River between the Watertown dam and the Craigie bridge, (had) a mean rise and fall of 9.6 feet (9′ 6.7″) with an extreme predicted range of 13.6 feet (13′ 6.7″), which at times of easterly winds and freshet flow of the river may be increased to 15 feet."[47] Since 9′ 6.7″ is but 1.7″ less than the mean rise and fall at the Navy Yard it seems possible that former differences may not have been very great and that we may rely upon the planes of reference established in Charlestown.

Evidence from the Lower Peat, particularly the diatoms and associated organisms, shows that probably the Amorphous Layer was formed above Mean High Water. The total amount of the submergence of this layer is 26′ 2.1″ in the eastern section (Fig. 14, *a* plus *b*), and 29′ 3.76″ in the western section of the building excavation, (Fig. 14, *e* plus *f*).[48] The Lower Peat has been traced to the west and various depths have been given. For example, under Dartmouth Street it lies about twenty feet below Boston City Base. Thus, in this area the amount of submergence is 30′ 5.2″ (Fig. 14, *g* plus *h*).

The Upper Layer, on the other hand, may have been formed in the intertidal zone or even at Mean Low Water. The implication is that, during the formation of the Lower Peat, there was a submergence which, at the maximum, may have been about 9′ 6.7″,—the Mean Rise and Fall of the tide, plus the amount the peat has been compressed.[49] However, the amount of submergence, as calculated for the Amorphous Layer, is the total amount for the locality about the building excavation.

The determination of the level at which the silt began to be deposited is

[47] Report of Committee, 1903, p. 11.

[48] These figures are taken from the top of the Peat Proper because no extensive measurements of the top of the Amorphous Layer were made. The consequent error of a few inches is negligible.

[49] The amount of compression cannot even be estimated and thus, the figures developed below will be subject to an error of this amount, cf. Footnote 36, p. 153.

fraught with many difficulties. It is a question whether the deposition of silt followed directly the deposition of peat or whether a period of time, during which there was some submergence, intervened between the arresting of peat growth and the beginning of silt development. That there was a drastic modification of the environment is illustrated not only by the change from peat to silt but by the appearance of distinctly marine diatoms and mollusks.

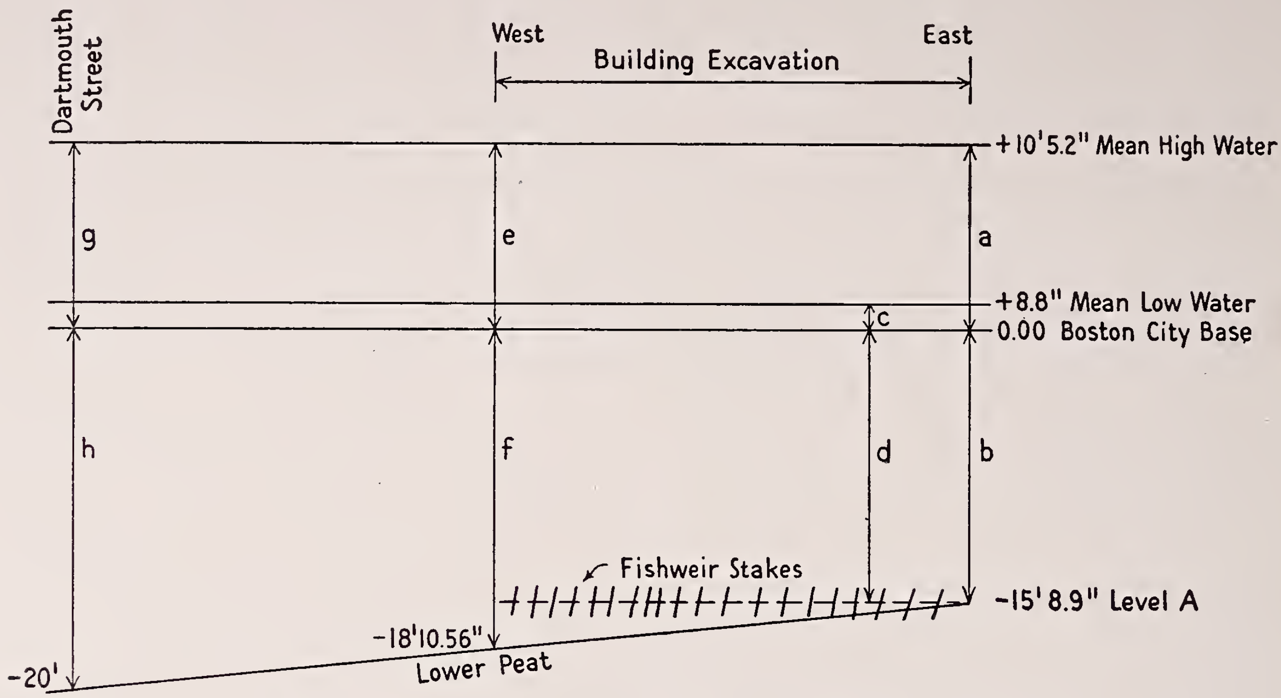


FIG. 14. Diagram to illustrate figures for submergence.

It seems possible that this change to marine conditions may have arrested the peat development but the change may have come about long before the silt began to be deposited. Under these circumstances, clear water would have run over the peat, leaving for us no records. Those that we do have would come from a time after the process of silt accumulation was well established.

The presence of the Fishweir stakes is of some significance in this connection. It has been shown that they had been driven through silt in the west and peat in the east (Level A, Fig. 5). Thus, at least by the time the Fishweir was built, the deposition of silt had begun. However, conditions were such that silt could only develop in sections where the peat was below Level A.

The significance of the oysters is of some interest here. These mollusks were found growing upon or very near the top of the Upper Layer. They might be able to thrive as they did while silt, in not too great quantity, was being deposited, but it seems probable that the oysters lived in reasonably

clear water and that they were exposed, at low tide, for only a short time. It seems unlikely that they would have developed upon the peat if it lay very high up in the intertidal zone. Thus the peat, at the time the oysters developed, was near the low water mark and silt accumulated at a rate which permitted them to develop into large sized adults before it smothered them. There is an implication that during the accumulation of the Lower Peat, preceding the deposition of the silt, there was a submergence amounting to the mean rise and fall of the tide.

The significance of the layer of Silty Peat is obscure. The layer developed among the first oysters and it is possible that the oysters were living among grasses and sedges before the silt buried them. It is more probable that the Silty Peat was simply a mixture of silt and vegetable material deposited upon the soft, churned up surface of the peat deposit upon which scattered clusters of oysters grew. Such clusters could originate from settings directly upon the surface or from oysters which dropped off the stakes and wattles. It seems plausible to assume that the process of deposition in the estuary was more or less continuous and that the change from peat to silt was caused simply by a change in general conditions. It is impossible however, to decide whether the process of silting began immediately after the peat stopped growing or whether a period of time intervened. From these particular data there appear possibilities suggesting a continuous deposition. However as explained below the presence of barnacles on the stakes militates against a continuous deposition unless the rate of accumulation was very slow while this stratum developed, as suggested by Knox.[50] This discussion takes on some degree of importance in its relation to an unqualified assumption made by Knox. In his attempt to date the deposits through the analysis of the pollen, he has assumed that there has been a continuous deposition of materials. If a period of time intervened between the peat and the silt, a gap in the pollen profiles of these deposits will appear, necessitating the development of a new series of dates. Of course this may work the other way, so that the waxing and waning of the percentages in the pollen profiles may be proof that no time intervened between the two deposits. Before such evidence can be accepted, however, the validity and real significance of the pollen profiles must be established.

The relation between the fauna and water level provides some additional information. According to Clench, the varieties of mollusks which were identified live "well down in the intertidal zone, at or near the low tide level," and "All species encountered . . . are to be found on mud and sand flats."[51] The exception to these statements, is that the mollusks could also live below

[50] P. 127. [51] P. 46.

the level of Mean Low Water. Additional, though more tentative, information can be gathered from the presence of the barnacle *Balanus eburneus* on the stakes. It seems probable that the thriving and mature specimens from the Fishweir did not live above Mean Low Water.[52] Because of these possibilities, it is necessary to interpolate into the history of the development of the deposit the implications of the successive positions of the tide levels.

The maximum submergence of Level A (Fig. 5) is determined from the assumption that the Fishweir was constructed when the peat lay at the level of Mean High Water. In this case, the total submergence, between the time when the Fishweir was constructed and the present day, amounts to 26′ 2.1″ (Fig. 13, *a* plus *b*). The second figure is based on the assumption that the Fishweir was constructed after the peat had been submerged to Mean Low Water. If this is the case, the total submergence since the Fishweir was built amounts to 16′ 5.7″ (Fig. 13, *c* plus *d*).

This second figure for the submergence of Level A seems more plausible, in that it would appear that silt did not accumulate until after the level was submerged to the level of Mean Low Water. The reason for this arbitrary choice, in the face of previous discussion, is found in the location of the barnacles and mollusks. No silt could have accumulated before *Balanus eburneus* had developed on the stakes. It is not necessary to argue that the full length of the stakes was submerged below Mean Low Water before any silt had accumulated. The barnacles are sparse on the lower section and concentrated in clusters on the upper sections of the stakes. Thus, there is considerable possibility that the upper sections were exposed to clear water longer than the lower sections were.

The situation is complicated by the presence of oysters and other mollusks. The oysters are adult forms several years old and, though the silt eventually smothered them, it was deposited slowly enough to permit them to grow to a large size. The existence of other mollusks suggests that they lived below Mean Low Water or that the level of the silt at first rose faster than the rate of submergence, so that it eventually caught up to the level of Mean Low Water.

During the course of the submergence of Level A, mud flats, which are now marked by the shell layers, developed. Whether these resulted from the temporary slowing up of the rate of submergence or whether they developed from changes in drainage in the estuary is not known. Regardless of the cause, it seems possible that the shell layers mark the culmination of periods

[52] Pp. 65–66.

during which large amounts of silt were being deposited in the area. Thus, strata lying between the layers accumulated so rapidly, either in the intertidal zone or immediately below it, that only scattered individuals of various species of mollusks, aside from the oysters, were able to survive. When rapid deposition stopped, the shell layers developed and the mollusks increased in numbers where they could live normally in the mud flat.

In terms of feet, measured from Mean Low Water, Shell Layer 1 developed after Level A had been submerged 1′ 7.0″, and Shell Layer 2 upon a submergence of 2′ 11.0″. Shell Layer 3 presents something of a problem because of its slope. It was formed when the area had been submerged between 8′ 10.7″ and 11′ 2.9″.

A submergence of this order will profoundly modify at least the topography and almost certainly the geography of a region. From the point of view of the present study, the changes caused by the drowning of the estuary are interesting if not important. These may be briefly but tentatively outlined from an incomplete perusal of the borings and other data.

It has been demonstrated that the process of drowning began before the Fishweir was built. As yet, little can be said of the changes in topography which took place, because the total amount of submergence is unknown. In any case, this drowning seems to have been responsible for the change from a brackish or fresh water environment to a marine environment. If we may assume that the Fishweir was built when Level A was located at Mean Low Water, we may, with some hesitation, describe the topography of the region. It seems possible that the Back Bay was, at this time, rather restricted. In Figure 1 an attempt has been made to indicate possible boundaries of the Lower Peat. While this boundary probably is far from accurate, it does suggest that the Back Bay was formerly more restricted than it was in Colonial times. In general, the area northwest of the stippling lay at or below Mean Low Tide and the area to the south lay above this level. Just how far above is a question but, at any rate, levels from the borings suggest that the land south of Tremont Street was dry. It is probable also, that what is now Fort Point Channel did not extend as far inland as it did in Colonial times; it may have been but a tiny brook. The height of land, now South Boston, was more closely connected with the mainland. The general picture is that Boston proper was connected to the mainland by a broad neck which was dry at all times. The area at the western end of the Neck, upon which the colonial marshes developed, may have been some six feet above high tide when the Fishweir was built. The early Back Bay and Fort Point Channel were not really bays or inlets but areas cut up by drainage channels, affected to varying degrees by the rise and fall of the tide.

As the process of drowning continued, several developments took place. The Neck became narrower, being encroached upon from both sides, until finally it ceased to exist and Boston proper became an island separated from the mainland at least at high tide. It appears that water may have run over the western part of the Neck when Mean Low Water lay at about −10′. This submergence enlarged the Back Bay in a westerly and southerly direction. It seems probable that the area west of South Boston was likewise submerged, so that the Back Bay may have had a tortuous connection with the sea at Old Harbor.

The results of this submergence should not be overemphasized for, during it, silt accumulated in all places except where the growth of the peat kept pace with the rising waters. Thus, extensive mud flats developed over much of the area and marshes continued to exist around the shores. Under such circumstances, drainage channels incised into the silt were probably the principle connections between such features as Fort Point Channel and the Back Bay.

As the drowning continued, more and more silt was deposited until the area was more or less choked. Marshes continued to develop about the shores and in various places in the estuary. The area west of Waltham Street (Fig. 1) became choked with silt which eventually supported a marsh and this marsh became the foundation for the road by which, at low tide, the first settlers of Boston could reach the mainland dry shod.

There is some question about the actual appearance of the bay in Colonial times. The descriptions may be interpreted in several ways. It seems certain that it was pretty well covered with water at high tide and that much of it was mud flat at low tide. That there were marshes about the shores is certain and the probable distribution of these has been indicated in Figure 1.

In view of the descriptions of the habitat included in special studies of the fauna,[53] this discussion of topography appears to be inadequate. During the course of the study it was hoped that some details concerning the topography of the Neck might appear and that periods when water ran over it might be correlated roughly with periods during which certain types of environment prevailed beneath the building excavation. It seems now that the estuary was cut off from Fort Point Channel by the Neck during the whole history of the Fishweir and the deposits surrounding it. It also appears that the Neck was open for a short period near the end of the time when the main oyster bed was flourishing and that this opening was at best tortuous. It is possible that this opening admitted some of the cooler waters which flowed over Shell Layer 3 but this cannot be ascertained with any

[53] Cf. Part II.

accuracy until more is known about the time when the opening in the Neck silted up.

The only other opening in the estuary is the present mouth of the Charles River between Charlestown and Boston. This opening has been present since early Post Glacial times. About the only modification of this opening which can be postulated is a possible broadening which may have taken place during the rise in sea level. It is true, however, that sand bars and shifting mud flats may have made changes in the details of its topography. Such changes could not have resulted in radical modifications of the environment in the neighborhood of the Fishweir. The changes which have been noted in the building excavation appear to be local in character, caused perhaps by shifting mud flats and the like. They appear to be only indirectly related to the major topographic modifications of the estuary.

Further study of Boston Harbor may show that during a period of low sea level it was partially cut off from the waters of Massachusetts Bay by banks extending away from the islands. Thus a connection between the estuary and the sea would be extremely complicated. Furthermore, the character of the connection would vary tremendously during a period of rising sea level. Unfortunately, it has been impossible to investigate any of the aspects of this problem.

THE CORRELATION OF EVENTS IN THE ESTUARY OF THE CHARLES RIVER WITH THE EVOLUTION OF THE MASSACHUSETTS SHORELINE

UP to this point, description and discussion has been restricted to phenomena discovered in the Back Bay and, to a more limited extent, on the Boston Peninsula. Before these observations can be of more than local significance, they must be correlated with events which took place along the coast of Massachusetts. By such correlation the developments in the Back Bay will take their proper place in the geological history of eastern North America.

Previously it has been pointed out that the various strata described were deposited subsequent to the glacial period. Consequently a discussion of the advance and retreat of glacial ice may be omitted. Further limitation of the discussion is made necessary because of the character and quantity of data which is available. It has long been recognized that the New England-Acadian region presents to the glaciologist a most complicated picture. The long sequence of events which took place during glacial times and thereafter have, in this region, been cramped into a relatively small space. In addition they have been modified by various characteristics of the terrain to a point where, all too frequently, exceptions to the continental sequences are really the rule. As a consequence of this it is necessary to assemble data, for the purposes of this study, from a series of analyses, the results of which are often contradictory, and which are only generally interrelated. With a very few exceptions, these analyses do not deal directly with the region adjoining the Boston Lowland. The outcome of such a procedure can at the very best be but hypothetical.

THE EVOLUTION OF THE MASSACHUSETTS SHORELINE FROM THE CLIMAX OF THE GLACIAL PERIOD TO THE PRESENT

Sea Level

At the climax of the Wisconsin Glaciation sea level was about three hundred feet lower than it it is at the present day.[55] As the ice melted and receded to the north the water thus released found its way to the sea and there

[55] Antevs, 1928a, p. 83; and others.

was a general, world wide, rise in sea level. Such changes in sea level have been called eustatic. The rate at which the sea level rose during Late Glacial times was not constant. "Unequal rapid rise of sea level in respect to time is evident, as the rate of ice wastage varied considerably and the depletion occasionally was even less than the supply."[56] By the end of Glacial times the sea had practically reached its present level.

Land Level

During this same period the land went through a more complicated history. The weight of the ice, as it spread over the land, brought about a depression of the land which varied in amount, at different localities, with the local thickness of the ice and the length of time it remained. Theoretically, at least, localities in the immediate vicinity of the ice front suffered some depression and, further to the south, there was an elevation of the land which was finally followed by subsidence to its present level. Two hypotheses have been advanced to account for these latter movements. One postulates that the weight of the ice caused the earth's crust along the front of the ice to bulge upwards. Then, as the ice retreated to the north, the bulge followed, as a wave, so that its southern margin subsided. The second hypothesis, explained by Daly,[57] postulates a low broad peripheral bulge in the earth's crust at the time of the maximum spread of the ice. As the ice cap was diminished, the crust responded with an elastic recoil which elevated the land beneath the ice and also the peripheral area. Following this, hinge zones developed in which some vertical shearing of the crust took place and the land beneath the ice was "punched" upward by deep internal forces in the earth, while the marginal areas slowly subsided.

Such a hinge zone or line has been located in the vicinity of Cohasset on the Massachusetts shore some twenty miles south of Boston.[58] This line is also the zero isobase, which runs slightly south of west. The location of this line upon the coast marks the spot where the shoreline of the glacial sea coincides with the present shoreline. It is therefore inferred that the land in the neighborhood of Cohasset was depressed some three hundred feet, the same distance that sea level had been lowered. South of this line the land was depressed, presumably, less than three hundred feet.

North of Cohasset, beaches and other phenomena are found above present sea level. These are due to the former presence of the sea, and from them

[56] Antevs, 1928a, p. 92. Possible fluctuations of sea level due to the gravitational attraction of the mass of the ice have been disregarded in this paper following Hörner, 1929, p. 142.

[57] Daly, 1934, pp. 122–124.

[58] Daly, 1934, p. 106; and others.

may be established the location of the former marine limit, or more simply, the shore line of the glacial sea. The location of this limit above the sea indicates that there had been a depression and submergence of the land in glacial times. The total lowering amounts to more than three hundred feet.[59] In short, these movements hinged in the neighborhood of Cohasset and consisted of an upwarping of the land to the north together with the presumable downwarping of the land to the south. Such movement may have been rapid, being sandwiched between long intervals of quiescence.[60]

The isostatic movement was the culmination of a process which began with the advance of the last ice. That part, which has been described, occupied the period of the recession of the ice. It probably ended about the beginning of the Post Glacial Period. As neither sea level nor the isostatic changes in land level took place at a constant rate the relationship between land level and sea level, as seen in the transgression and regression of the shoreline, was probably extremely complicated. However, the end result of the process was that, theoretically, the land came to rest at approximately its present relation to sea level. Actually, the present relation between land and sea may not have come about until another cycle of movement, superelevation and subsequent sinking of the land, had been completed. Although these movements are described separately, it will be seen that since they overlap in time, it is difficult to separate the various phenomena and ascribe each to one particular time or cause.

Developments Subsequent to the Adjustment of the Marine Limit

Sea Level

As the ice continued to melt there was an eustatic rise in sea level, which reached its maximum when the area and quantity of the ice was at a minimum. Whether there has been a significant fluctuation in sea level since it reached its maximum limit along the New England shore, is a question which cannot be answered satisfactorily. Johnson[61] questions a recent, world wide eustatic sinking as a cause of many characteristics of the New England shoreline and thus implies, guardedly and with some forensic qualification, that the present stand represents the maximum post-glacial rise in sea level. Daly,[62] on the other hand, attempts to demonstrate that sea level over the

[59] For identification and measurement of the marine limit see Hörner, 1929, p. 139 et sec.

[60] Antevs, 1928a, p. 92.

[61] Johnson, 1935, passim and p. 233. For further discussion see Hörner, 1929, p. 143.

[62] Daly, 1934.

world reached its maximum height during the Post Glacial Optimum, a period of mild climate which prevailed between five thousand and seven thousand years ago. Since that time, according to this theory, there has been a fall in temperature resulting in the expansion of glaciers and polar ice sheets with the consequent impounding of water. This recent removal of water from the sea is thought to have resulted in an eustatic sinking of sea level, amounting to about sixteen feet. What is believed to be the sixteen foot shoreline has been identified along many coasts but, as yet, this shoreline has not been identified along the Atlantic coast of North America. A few scattering observations and tentative discussions may indicate that such a level may be identifiable, particularly in the northerly sections of the New England Acadian region but there exists no satisfactory data regarding the Massachusetts shoreline. It may be added, however, that various provocative phenomena, as yet unanalyzed, are observable, particularly in the western part of the Cape Cod region. A study of these and their relation to the rest of the coastal region should produce a major contribution to the geological knowledge of eastern North America.

Land Level

The second movement of the land has been called superelevation. This process of upwarping affects the land differently than the isostatic changes noted above. In the case of Massachusetts, the region, including the zero isobase, was elevated, as well as were regions north and south. Following this uplift, the land subsided to its present position.

The geologists who have studied the Massachusetts coast have not distinguished superelevation from the isostatic movements. However, such rise in the elevation of the land has occurred in other glaciated areas, particularly Scandinavia and Denmark, and, theoretically, it accompanies the recession of all major glaciations.[63] Granted that the theory is valid, superelevation should have occurred in New England. Daly believes that such movements did take place in the region, and presents as evidence various data including observations on the distribution of plants between New Jersey and Newfoundland.[64] Hörner also mentions the distribution of mollusks which might be interpreted as indicative of superelevation.[65] This evidence is as yet, unfortunately, not sufficient to prove the case.

Such studies as have been made along the Massachusetts coast have produced scattered but nevertheless conclusive evidence that the shore line once stood above the present one. There are drowned river mouths which have not yet become filled with sediment and there are submerged forests

[63] Daly, 1934, p. 84, et seq. [64] Daly, 1934, p. 108. [65] Hörner, 1929, pp. 140–141.

which must have grown when the sea was lower than it is now.[66] In addition, peat beds, such as the Lower Peat in the Charles River estuary and those reported at other locations, particularly south of Boston, are found below sea level.[67] These and other occurrences could not have come about unless the land was once higher, relative to sea level, than it is now.

The question whether this high level of the land was due to superelevation or not is, of course, a moot one. It is possible that some of the evidence cited as proof, is the work of earlier low stands of the sea. These phenomena may belong to the period when fluctuations, or isostatic changes in sea and land level were occurring. A second possibility is that some of these phenomena were brought about by a combination of superelevation and isostatic change. In conclusion, it is permissible to submit the hypothesis that the more ancient evidences of the elevation of the shore line were the result of isostatic changes combined with superelevation but the later evidence can be ascribed almost wholly to superelevation and the sinking which followed it.

Developments in Modern Times

The question whether or not there has been a relative submergence of the land during the last few hundred years and whether this submergence is continuing at the present time has been argued back and forth for years. The ultimate solution of the problem hinges upon the correlation of a mass of data which comes from many widely divergent fields. At the moment, the data appears to be incomplete and in any case it is extremely contradictory. The many investigations contribute to two main divisions of the discussion: (1) Changes in sea level and (2) Changes in land level.

Available data relative to sea level seem to agree pretty generally. Gutenberg, after a complicated computation, finds that there has been no recent world wide change in sea level.[68] Iselin practically agrees with this conclusion.[69] He says that, strictly, oceanographic factors can account for sea level changes amounting to but a few inches. Further, he says that one is safe in assuming that the level of the sea at Boston has remained fixed, within a few inches, over the last several hundred years.[70] Unless data can be presented to contradict these ideas, recent changes in the relation between land and sea must be stated in terms of the movement of the land.

The principle arguments for submergence of the land in the Boston Lowland within historic times, have been advanced by Freeman. He calculated

[66] Antevs, 1928a, p. 93; Lyon, 1934; etc.

[67] Hörner, 1929, p. 139; Shimer, 1918, p. 462; Worcester, 1914, p. 405; Johnson, 1925; Part I; etc.

[68] Gutenberg, 1933, p. 460. [69] Iselin, 1940. [70] Iselin, Correspondence, 1941.

that a bench mark on the dry dock at the Charlestown Navy Yard had sunk 0.71 feet in seventy-two years. He believed that this indicated a submergence of the land at the rate of "a little more than one foot per century."[71] Aside from these observations he adds his belief that the level of tide gauges has changed. Also that many rocks about the edges of Massachusetts Bay are found to be from one to two feet lower, in relation to extreme tides, than they were about ninety years before he wrote. Furthermore, he adds that extreme tides in great storms appear to show progress toward greater heights. As additional proof of recent subsidence, he notes that submerged trees were also found standing in salt marshes. LaForge[72] concurs in the opinion that the land is now being submerged at the rate of one to two feet per century.

Many authors, particularly in the geological field, hold that evidence against continuous recent subsidence is accumulating and they believe that the submergence of the coastline may have ended between one and three thousand years ago or more. Since that time, the relation between land and sea has, according to their ideas, changed but little.

Freeman's argument, based on the Charlestown dry dock, has been severely criticized.[73] This criticism, if not sufficient to vitiate his results, does throw much doubt upon them. A memorandum from James W. Goldthwait[74] says, in respect to the tide gauge on the Charlestown dry dock, that the measurements fail to show any change. One principle difficulty is that the original relation of the gauge staff to the tide level is uncertain and thus it is impossible to reach any valid conclusion. Freeman's argument that there was a "progressive increase in tidal height of greatest storms" is hardly worthy of discussion. Such tidal heights are due to so many different, usually extremely local, fortuitous circumstances, that they can be of little significance in this instance.

The observation by Freeman that many submerged rocks about Massachusetts Bay are evidence of contemporary submergence appears also to be faulty. Measurements made by J. W. Goldthwait at Marblehead,[75] an area which certainly would be affected by this supposed late subsidence, appear as evidence that the coast has been stable for at least as long as records have been kept. These measurements are somewhat rough and thus it is con-

[71] Freeman, 1903, pp. 529, 588. [72] LaForge, 1932, p. 87.

[73] Report of Committee, 1903. Schurman, 1928, discusses the affects of frost action and repairs on the tide gauge measurements on the dry dock.

[74] Goldthwait, J. W., 1940, quoting; Schurman, 1928, pp. 1–10; and his personal correspondence with various authorities.

[75] Goldthwait, J. W., 1938a, for similar measurements cf. Goldthwait 1936b.

ceivable that normal fluctuations in tidal height may have obscured evidence of a slight subsidence. However, even if historic subsidence has been off-set by such factors, the amount of subsidence possible is no where near the one to two feet per century which has been postulated by some students.

Various other places on the coast have been investigated and the observations have been used to prove, on the one hand, coastal subsidence, and on the other, coastal stability. The question of the recession of the coastline in front of the fortification at Louisburg on Cape Breton Island has been discussed at length by J. W. Goldthwait.[76] It seems that the encroachment of the shore upon the fortifications has not been caused by coastal subsidence but to the erosion of the ramparts by the sea. Goldthwait's opinion that there is no evidence of coastal subsidence since 1745 at this location seems to be correct.

From a study of the shorelines bordering Cape Cod and at Nantasket beach, Johnson[77] infers that the relative levels of land and sea have not greatly changed. He also finds the shoreline youthful, indicating that the sea has not stood at its present level long enough for the waves to cut into the weak material. In other words, it would seem that a few thousand years must cover the duration of the present cycle. Goldthwait[78] adds the information that "the crest line of the ancient West beach (a section of Nantasket Beach) . . . is actually about two feet lower than the crest of modern Nantasket Beach." If the age of West beach, as some believe, is between one thousand and three thousand years, the lowering should be ten to thirty feet, provided the rate of subsidence was one foot per century. The two feet which is actually the difference is certainly not of this order. It may be pointed out, however, that beach crests are at best imperfect water-marks; their crests are built to variable heights above sea level according to exposure, strength of beach building storms, and the kind and amount of material available at the time. They are not reliable bases upon which to measure changes of level of the scale here concerned. West beach, then, has little bearing upon the question of modern subsidence beyond suggesting that if there has been any at all, it has been much less than one foot per century.

Various other measurements of several types of phenomena have been offered by many geologists. A general balancing of these records leaves the impression that strictly geological data points to the eventual conclusion that there has been little or no subsidence in recent years. In an interesting combination of geology and archaeology, R. P. Goldthwait has made a

[76] Goldthwait, J. W., 1924. [77] Johnson, 1925, p. 488.
[78] Goldthwait, J. W., 1940.

detailed study of the location of the large oyster shell heaps left by the Indians at Damariscotta and New Castle, Maine. He comes to the conclusion that "It is almost unavoidable: sea level has been stable here during the 1000 years recorded by the heap."[79] The date developed by Goldthwait is open to serious criticism but it is not inconsistent with present unqualified and probably unfortunate guesses prevalent in the archaeological world. His assumption that the shell heap would have been below tide level, had recent submergence taken place, may also be questioned. Aborigines have been guilty of the most illogical behavior and there is no reason for believing that these shell heaps could not have been built some distance above tide level, to be submerged to their present locations in recent times. His argument that if submergence had occurred, a rocky barrier in the estuary below the heaps might have prevented the growth of the oysters is a little more convincing and, with some reservation, it seems possible that there has been no change in land or sea level in the Damariscotta section of the coast of Maine for some time.

J. W. Goldthwait has called attention to an analysis of tilting made by Gutenberg in 1933. In this work, reference is made to variations in sea level, as indicated by the annual average of the hourly heights of tide on tide guages along the Atlantic coast. At Baltimore, Maryland, the curve made by plotting the mean gauge height of the tide has been interpreted as indicating a rise in sea level between 1900 and 1930. This curve can also be interpreted as a rise in sea level between 1900 and 1920, followed by a lowering between 1920 and 1930. At Fort Hamilton, New York, the curves show an upward trend between 1900 and 1920. At Portland, Maine, the curves of gauge readings show a lowering of sea level beginning just after 1900 and ending in 1930. Following his conclusion that sea level has been stable in recent years, he says, "The eastern part of North America seems to show a rise of land in the north caused probably by uprising following the melting of the ice after the Ice Age."[80] This statement and the accompanying data imply that the Atlantic coast is still being affected by changes initiated thousands of years ago. According to Goldthwait,[81] the data is more logically interpreted as proof of the variability of mean tide level. In this way it describes the rise of sea level at first and then a fall at all three places.The fluctuations analyzed by Gutenberg may be explained as tidal fluctuations of a periodic and non-periodic type. They do not constitute proof of either crustal elevation or depression. Curiously enough, the interpretation offered by Gutenberg is the only one which suggests a rise in the level of the

[79] Goldthwait, R. P., 1935. [80] Gutenberg, 1933, p. 460.
[81] Goldthwait, 1940.

land, relative to that of the sea. This is the only case in which this interpretation has appeared. All other data points to a submergence of the land.

The evidence from the study of local marshes should throw much light on the question of recent continued subsidence but, at the present time, this evidence is incomplete. Johnson has summarized and discussed at length the relationship between peat bogs and coastal subsidence, or rise in sea level.[82] With certain exceptions in interpretation, he adheres to the theory of marsh development in New England first advanced by Mudge and later corroborated by Davis and, for the marshes in the Bay of Fundy, by Dawson.[83] This theory was stated by Mudge, "The saline grasses grow only above ordinary high water mark, and as the roots in the lowest part of the soil, even eight or more feet below the surface, are in their natural position, showing no distortion, we must conclude that their *situs* was above high water line, and that the subsidence has been so gradual that the growth of the plants has never been interrupted." The grasses here referred to are *Spartina patens* and a few other species occasionally associated with it. This grass grows in a zone having a vertical range of about two feet which, in relation to tide level, occurs from a little above to a little below the level of Mean High Water. The remains of this grass has been found in situ below the level of low tide on many New England marshes and thus the conclusion that the shoreline has been submerged seems inescapable.[84]

It seems, furthermore, that the submergence has been gradual and progressive, never rapid enough to destroy the growth of *Spartina patens* and initiate a new and different cycle of marsh formation. In addition, fresh water peat has been found but a foot or so beneath marine peat which developed over the high tide mark. Such data suggest that the submergence has been continuous, and that it may have taken place in very recent times. Similarly, the presence of stumps in the marshes and also dead trees standing about the edges of marshes suggests that progressive submergence has lasted to the present day. However there are many factors, such as influences of changing topography, which must be considered. Therefore it is wise to await further study of these data before coming to any conclusion.

Chapman has found that it requires approximately 2290 years for a marsh to develop to maturity.[85] The validity of this figure may be ques-

[82] Johnson, 1925, Chapters xvi–xviii.

[83] Mudge, 1858; Dawson, 1868; Davis several papers between 1908 and 1913, quoted by Johnson, 1925, p. 560.

[84] There is an extensive bibliography dealing with this aspect of the study of marshes. Cf. Chapman, V. J., various papers; Nichols, G. E., 1920; Knight, J. B., 1934; and others.

[85] Chapman, 1938, p. 381.

tioned on several grounds. It seems obvious that conditions on different marshes may differ greatly, so affecting the speed of growth. However, it is possible that contemporary marshes reached their present level several centuries ago[86] and that their development has required a length of time which may be measured in a few thousands of years. The work of Goldthwait on the marshes at Ipswich[87] makes this possibility worthy of considerable future investigation. It was discovered, through measurements and comparison with old charts, that "the upland vegetation has not only held its ground but has tended to reach out over the surface of the marsh." This observation and others on marshes scattered along the coast, has led Goldthwait to hypothesize, "these records seem to deny a present sinking of the coast except in the limited sense that loose deposits pack down while they form."

In summarizing the data dealing with the question of historic subsidence, we find ourselves faced with a dilemma. The opinions of geologists are divided; some admit that there has been a recent subsidence of the coast and others take great pains to show that probably there has been no change in level for a thousand years or more. Studies of coastal marshes between New Jersey and Nova Scotia produce evidence that, not only has the shore line submerged, but it probably is transgressing upon the land at the present time. The submergence, as evidenced by the marshes, has been admitted by various geologists but they insist that this movement ended two or more thousand years ago. They answer the hypothesis of historic sinking with hypothetical local shrinkage of underlying deposits, due to various geophysical phenomena, and also with hypothetical local changes in tide levels, which came about by minor modification of the topography.

One factor involved in the submergence of the surface of the marshes is the shrinkage or consolidation of the deposits. Studies of such shrinkage are only in the exploratory stage and so no facts of general significance can be deduced.

Obviously, more studies of the marshes are needed, and, even more obviously, at least to one outside the geological field, the geological arguments against recent subsidence require further documentation. At the moment, the issue is partially obscured by the many complications and by a number of contradictory hypotheses. Because of this, it is not possible to decide whether or not subsidence of the coast line is progressing at the present moment. It does seem possible that the data from the marshes may be leading up to the eventual conclusion that subsidence is still taking place.

[86] Johnson, 1925, p. 585.
[87] Goldthwait, J. W., 1936a.

The major reason for discussing the present status of the problem of the recent subsidence of the land, is because of its relationship to the submergence of the Fishweir. If, as many geologists hold, submergence ended some one to three thousand years ago, the Fishweir was built before this period. If, on the other hand, the testimony of the marshes proves to be correct, the submergence of the Fishweir would be included in developments which have continued to the present. Thus calculations would begin with the present day. Choice of the latter alternative need not necessarily affect the dating of the structure, for the submergence may have been continuous over a long period of time, rather than having proceeded for a relatively short time, to stop one thousand or more years ago.

Summary

The foregoing discussion, or resumé or data relative to the evolution of the Massachusetts shore line, has brought out the fact that in general, following the retreat of the glacial ice, there have been oscillations of the relative level of land and sea. There has been an emergence followed by a submergence of the land. The probability that the latest change in relative levels, submergence, has virtually stopped is contradicted by equally convincing evidence that the land is still being submerged. If submergence has been arrested, the movement is said to have stopped several thousand years ago. Problems of time involved in theoretical contemporary submergence have by no means been answered. It is not known whether the age of the present day marshes may be measured in terms of centuries or thousands of years.

The character of the rise of land to the north of Cohasset in post-glacial times is all important in its relation to the present study. It has been suggested that the rate of rise may not have been constant. If this is so, the transgression of the coastline by the sea must have been irregular. Even more important is the probability that superelevation and subsequent depression took place, so complicating the history of the modification of the shoreline during the process of elevation. This superelevation complicates the relationship between the rising land and the rising sea level. If we introduce the possibility of an eustatic lowering of the sea, subsequent to the Post Glacial Optimum, the possibility of coming to some conclusion appears to be hopeless. It actually becomes hopeless when it is discovered that adequate geological studies of these particular phenomena are few and far between. The only recourse left is to speculate about the succession of events. Such speculation is offered in the form of an hypothesis which, naive as it is, may constitute a statement for further discussion.

THE PLACE OF THE CHARLES RIVER ESTUARY IN THE EVOLUTION OF THE SHORELINE

In reviewing the situation in the building excavation, which by inference is representative of a large part of the Charles River estuary, there appear certain landmarks which are hypothetically indicative of the relation between land and sea level. 1. The blue clay was deposited in the sea and the presence of foraminifera suggests a certain depth of water, probably greater than the range of tide. 2. The blue clay emerged above sea level and drainage channels were incised into its eroded surface. Possibly also this surface was oxidized during this time as Crosby holds.[88] 3. A process of submergence began. Soon after the initiation of this cycle, peat, of fresh or slightly brackish water origin, developed upon the higher sections of the blue clay and silt of marine origin developed on the lower sections of the surface. 4. Submergence continued; peat deposits became distinctly of brackish or actually marine origin and they were interstratified and covered with marine silt. In some areas no peat was developed and only silt accumulated. During these latter developments the Fishweir was constructed. This submergence continued at least into geologically recent times and possibly to the present day.

The location of the Fishweir in a period of rising sea level appears, in the light of present possibility and rarer fact, to be impossible. The data on climatic evolution, to be discussed below, shows rather conclusively that the Fishweir was built subsequent to the Post Glacial Optimum. If there has been a change in relative level since this time, it should be, theoretically, in the direction of emergence and such, certainly, has not occurred at this site.

About the only way these conditions could develop is through fluctuations in land level of a range sufficient to compensate for the presumed eustatic lowering of sea level subsequent to the Post Glacial Optimum. If sea level has not been lowered, then changes in the level of the land were not as great. Such fluctuations are theoretically possible if the theory of superelevation and subsequent depression can be applied to the region.

Concerning the submergence, which took place regardless of its cause, Hörner has written, "The rapid regression and the numerous and, in some cases, rather good-sized deposits of peat below the present sea level suggest that the shore lay outside its present position for a considerable time.[89] At length the regression of the shore line was followed by transgression drowning peat bogs and river valleys, and ultimately shifting the shore to

[88] Crosby, 1903a, p. 346.

[89] Antevs, 1928a, p. 93 says, "The shore line may have lain outside its present position for about one half of the late glacial and post-glacial time, or until recently."

its present position."[90] Hypothetically, after the blue clay was deposited it was superelevated. During this time it was eroded and possibly oxidized. In due time the depression of the land, which follows such superelevation, submerged the blue clay and, during this submergence, the various layers of peat and silt accumulated as their proper environments evolved.

Actual chronological details of the movement are scarce, it is not known exactly when the uplift reached its maximum. Hörner suggests that the entire uplift was rather rapid and without pronounced interruptions, and further suggests the possibility that the modern stand may have been reached some time ago.[91] In making this suggestion he quotes Antevs' discussion of the distribution of mollusks. The significance of the distribution of mollusks may be questioned in this instance. Certainly the data does not appear to be as trustworthy as the testimony of the marshes, from which it may be deduced that the submergence has continued to fairly recent times if not actually to the present day.

To account for this movement by assigning it to the depression of the land following superelevation is, of course, making an assumption on the basis of very scanty evidence. It also does great violence to the assumption that American and European developments are analogous and coeval. If we could forget this latter assumption, and consider the possibility that developments in America lagged behind those in Europe, the hypothetical interpretation of the data from the Charles River estuary becomes more acceptable. It might be assumed that the present coastline of North America has been depressed, perhaps is still being depressed. It has not experienced the plastic recoil of the earth's crust, or elevation, which has been recorded along the shores of the present Baltic Sea.

In a final evaluation, it must be clearly recognized that this hypothesis is based purely on other hypotheses and so is proposed only as a thesis for further debate. Certain additional points, relative to this discussion, are worthy of consideration. At the very outset, vague ideas concerning the possible date at which man arrived in New England tend to limit the discussion of events. Furthermore, the question of climate surrounds the argument with certain hypothetical limits. In the first instance, prejudice in favor of the idea that man must be recent in New England is unfortunate. If men lived in North America some twenty-five thousand years ago, as suggested by Bryan and Ray, or even ten thousand years ago, according to Antevs,[92] there is no reason why they could not have wandered into New

[90] Hörner, 1929, p. 140.
[91] Hörner, 1929, p. 140. Quoting Antevs, 1928b.
[92] Bryan, K. and Louis L. Ray, 1940. Sayles, E. B. and Ernst Antevs, 1941.

England at any time after the region became habitable. Thus, there is no reason, other than those mentioned in this discussion, why the Fishweir cannot boast of some antiquity.

Secondly, climatic changes, accompanied by tentative dates, are, unfortunately, overpersuasive. The very few studies of climate in the New England region demonstrate the probability that there have been, during past millennia, many and varied changes. To date, such changes have only been tentatively suggested for certain restricted areas in New England. Such data does not permit a general statement concerning the evolution of the New England climate as a whole. The tendency to correlate these local changes with developments which have taken place over a wide area in Europe is unfortunate. The local American data is inadequate, and, what is more important, the proof of a correlation of events in America with those of Europe is very dubious at the moment. There are certain analogies in development and very rare, vague and tentative proofs of contemporaneity, but the idea that developments in America are coeval with similar ones in Europe appears as an *a priori* argument. Thus, at the outset of the argument, arbitrary limits of time and conceptions of climatic change based upon an assumed correlation between America and Europe establishes bounds to the discussion, which might obscure the ultimate solution of the problem.

THE EVOLUTION OF THE ENVIRONMENT AT THE BUILDING EXCAVATION

An orderly study of the ecology of the organisms which were found in the various levels above and below the Fishweir presents a picture of changing environment. This picture may be discussed profitably from at least two angles. The first is the very restricted local development. The second is a discussion of how this local picture may be correlated with developments of wider scope. We may proceed with a summary of the evolution of environment in the building excavation and discuss each in the order which has been established.

The Blue Clay

At least the upper layer of the blue clay was deposited in some depth of salt water. Ten species of foraminifera which commonly live near the bottom and four pelagic species were identified. Two of the latter indicate that the water, under which the blue clay was deposited, was somewhat warmer than the present waters of Massachusetts Bay.

The Amorphous Layer of the Lower Peat

The diatoms from this layer indicate that the peat grew up in a predominately fresh water environment which was slightly modified by brackish water. Partial identification of other materials is responsible for the opinion that this peat was autochthonous, developing close to or perhaps above Mean High Water level.

The Upper Layer of the Lower Peat

Diatoms are the principle orgainsms which have been identified in this layer. These indicate a change in conditions from fresh water to brackish and marine. These and other data are responsible for the opinion that this layer, made up of allochthonous material, was deposited in the inter-tidal zone probably near Mean Low Water. A comparison of the diatoms with those found today in Duxbury Bay suggests that probably the water was somewhat warmer than it is at the present moment.

Silt between the Lower Peat and Shell Layer 1

The diatoms in this layer testify to the development of marine conditions characteristic of river mouths. The rare fresh water forms appear to be more or less accidental. The mollusks substantiate this conclusion, including even the possibility that some small amount of fresh water found its way to the location. The assemblage of species of mollusks suggest that, while this layer was accumulating, the water in the estuary was warmer than that now found in Boston Harbor.

Shell Layer 1

From a study of the mollusks found in this layer, it seems that the environment was the same as the preceding one. Similarly the diatoms, according to Linder, indicate that the environment continued to be marine or brackish, but possibly the water was a little warmer. The presence of *Balanus eburneus* on the Fishweir stakes is very inconclusive evidence of warmer water conditions. The discovery of the marine borer, *Bankia gouldi*, in the stakes is, according to Clapp, rather definite evidence of the presence of water which was warmer than the present day. The difficulty with the evidence of the borers is in determining its association with a particular layer. Certainly, the conditions preceded the deposition of Shell Layer 2 and possibly they preceded Shell Layer 1. Nelson, commenting on the association between the oysters and diatoms, implies that the change to marine conditions brought cooler water which may have resulted in fewer oysters

and they grew more slowly. The disagreement here, concerning water temperature may be arbitrarily solved by suggesting that the preponderance of evidence, i.e. the mollusks and diatoms, and tentatively, the barnacles and marine boreres, indicates little or no change in temperature and we may assume that it remained warmer than it is at the present time.

Silt between Shell Layers 1 and 2

The conditions as indicated by the mollusks found in this layer indicate that there was little or no difference in temperature when compared with the preceding one. The diatoms however, indicate that the marked changes noted in the overlying layer had already begun.

Shell Layer 2

The evidence of the fauna and flora of this layer shows clearly that this deposit is distinctly marine. Further, it is clear that there occurred a change in temperature which was more marked than any noted heretofore.

Nelson, in commenting on the oysters, says that Shell Layer 2 represents the "Golden Age" not only for the oysters but for the other mollusks. This is certainly true, for the oyster bed began its greatest development on this layer and continued to expand horizontally and vertically through the next four feet. In commenting on the list of mollusks supplied by Clench, Nelson notes the presence of *Mytilus edulis* and *Spisula solidissima* and says that the appearance of these two genera indicates a definite swing away from the warm brackish water conditions of a river mouth to the more exposed colder, higher salinity conditions of the sea. According to Linder, the marine diatoms noted in this layer suggest the prevalence of colder water which may have been modified by the sun during periods when the diatoms grew and reproduced.

At first sight, the interpretations of Clench and Nelson seem to disagree, but actually they do not. *Mytilus* and *Spisula* are perhaps cooler water forms but they still tolerate warmer water conditions. They are found as far south as North Carolina. *Triphoris perversa nigrocincta* is a distinctly warm water form but at present it is found as far north as Wellfleet, Massachusetts. It can tolerate a certain amount of cooler water. But one worn specimen of *Triphoris* was found and there is a possibility that it was washed out of an earlier deposit or that it may have been able to exist under some very local, favorable condition. While the indications of a change to cooler temperature are acceptable, it seems certain that modern conditions had not yet been reached.

Above Shell Layer 2

The flora and fauna found in the deposits above Shell Layer 2 and including Shell Layer 3 indicate that marine conditions continued and that water temperatures approached those of the present time. The presence of oysters, especially in the main bed, constitute evidence that the water was slightly warmer than the present day, at least during the season when they reproduced. The character of the diatoms suggests that there was a sudden change in the environment at the time the top of Shell Layer 3 was laid down. Unfortunately, the samples collected were inadequate and they did not produce sufficient data to describe this change.

Above Shell Layer 3, Including the Upper Peat

During the development of this stratum the oyster bed petered out. To account for this, Nelson postulates either a change in climate resulting in a lowering of water temperature or a change in topography that permitted the influx of cooler sea water.

The Upper Peat was laid down under marine conditions, at some time previous to European colonization, and, it seems likely, that water temperatures were not significantly different from the relatively cool temperature of the present day.

Summary

The fauna and flora indigenous to the deposits themselves indicate a change of environment. Such a change appears, on the whole, to have taken place at a rather consistent rate, with the possible exception of developments during the deposition of Shell Layer 2. The amount of this change is not really very great.

The presence of warm water forms of foraminifera in the blue clay should not be overemphasized. The ecology of these organisms is imperfectly known and by no means understood. However, there is some data which suggests that warmer water conditions may have once existed in some sections of the western Atlantic Ocean. The assumption that these conditions obtained all along the east coast of North America is, of course, questionable.

Summarizing present knowledge of foraminifera, in the light of a study of six cores of the ocean bottom east of the one hundred fathom line off Cape May, New Jersey, Phleger has made several qualified suggestions. He says, "that there existed during some part of postglacial time warmer surface water than at present overlies these positions on the continental slope. This may represent a local postglacial shift of the Gulf Stream nearer the

shore or some other, smaller area of water. Another possibility is that it represents general warmer surface water conditions. The foraminifera concerned in this observation are pelagic types, and therefore the possible interpretation can apply only to the surface-water layers."[93]

The Amorphous Layer, deposited in fresh water and flooded with brackish water, suggests its origin at high tide. Differences between this layer and the overlying Upper Layer, deposited in the intertidal zone, are principally due to the change to a marine environment. Little in the way of temperature change is involved.

The first silt was deposited under more or less marine conditions and, as the deposits increased, their marine character became more evident. However, there were significant fluctuations between brackish and marine conditions. Such fluctuations appear as changes in the amount of fresh water from the Charles River or from seepage, or perhaps drainage, from Beacon Hill. Possibly changes in topography were, as Linder suggests, responsible for the variations in the influence of fresh water upon the "normal" marine, river mouth environment.

During the process of deposition, there were changes in the temperature of the water. These were reflected by the diatoms in particular but other organisms substantiate the conclusions for the most part. It seems that the water was warmer than at present during the time the materials between the Amorphous Layer and Shell Layer 2 were being deposited. Following this, the temperature of the water cooled off until, at a period probably preceding the development of the Upper Peat, the conditions approximated present conditions in Boston Harbor.

Another question which must be considered is the significance of the location of this shallow water, mud flat environment. The map (Fig. 1) shows the estuary at the bottom of Boston Bay and Boston Harbor. It is removed some distance from the open sea of Massachusetts Bay and it is somewhat protected from this bay by the islands in the harbor and also by the present narrow channel between Boston and Charlestown. The effect of such protection may be gauged by the temperatures taken in 1903, "the water at high tide near Harvard Bridge is on the average eight degrees warmer than at Boston Light."[94]

Even the most casual glance at the map (Index Map, Fig. 1) shows that the estuary must always have been more or less protected from the open sea. At the time of the lowest sea level recorded in this study, the estuary

[93] Phleger, 1939, pp. 1415–1416.

[94] Report of Committee, 1903, p. 18. Boston Light is located on one of the outermost islands in the harbor.

was even more protected than it is at present. Under these conditions, it is reasonable to expect that the water would be warmer than the sea, at least during the milder parts of the year. The cooling off of the water can easily be explained by the raising of sea level, allowing the naturally cooler waters of the harbor and Massachusetts Bay to inundate the estuary. This situation might further be explained by postulating that the estuary was a relict area in which warm fauna and flora, originating in a preceding, really warmer period, survived and continued to exist in a later, cooler period. However the problem is not quite as simple as this. The possibility that, at the time the Fishweir was built, the estuary was smaller should not be ignored. The water from the harbor may not have been warmed as much as it was just before the Craigie dam was built. There was less of it and the restricted area of the mud flats did not supply a great expanse over which the water might have been warmed by the sun. Thus, excepting extremely local "pockets," there may not have been a significant difference in temperature between the estuary and the harbor. The principle difference would have been, of course, in the salinity of the water.

Because of the tenuous evidence of the foraminifera, there is some possibility that the sea water, even outside the harbor, in Massachusetts Bay, was warmer than it is now. Furthermore, during the general cooling off of the water in the estuary, there have been fluctuations in salt and brackish water and possible slight fluctuations in the temperature of the water. Thus the changing conditions are not wholly explainable by postulating that an inundation of the estuary by sea water, which maintained a stable, marine, cool temperature, affected the flora and fauna. Though the evidence is tenuous, there is a suggestion that the whole environment, tentatively including climate, may have been a little milder when the Fishweir was built than it is now.

A RÉSUMÉ OF PRESENT IDEAS CONCERNING THE EVOLUTION OF CLIMATE IN EASTERN NORTH AMERICA

THE evolution of climate must be approached from many angles and, before any solution of the major problem can be suggested, the solutions of the various subsidiary problems must be correlated. Several arbitrary divisions of research are, to some degree, fundamental to such a study. Of these, Pollen Analysis is perhaps the most inclusive and, at the moment, the more popularly known.

Pollen analysis is based upon the assumption that the pollen of trees and other vegetation preserved in a deposit is an indication of the type of climate which prevailed when the deposit was laid down. The evolution of climate may be followed in pollen profiles, which are graphs recording the percentage of pollen grains of different species, relative to a succession of deposits. The significance of these profiles cannot be made clear until many technical and methodological modifications have been applied to them.

Climate affects a wide area and it has been found that the vegetation of a locality is apt to be modified by local conditions. Further specific characteristics of a region are responsible for variations which differentiate it from surrounding regions. Because of this, pollen profiles have to be constructed for specific sites. The profiles from sites within a region have to be correlated, or, as is said, "matched," to produce an account of regional developments. Finally, profiles from neighboring regions have to be matched before the evolution of climate over an area can be described.[95]

The account of climatic evolution, based on changes in vegetation, by no means supplies all the necessary information. Other organisms, such as diatoms and mollusks, supply important data regarding the character of the environment. In addition, an analysis of the deposits themselves supplies significant information in respect to the conditions under which the organisms, including the vegetation, existed.

Pollen analysts and others included in the widest definition of the field of research have found it possible to apply relative and, to some extent, absolute chronologies to their accounts of the evolution of climate. This has been done with some success in northern Europe, where the results of detailed geological and archaeological researches have been applied to data

[95] For an account of techniques and methods employed in Pollen Analysis see Godwin 1934.

regarding the history of the vegetation.[96] Critical points in climatic evolution have been correlated with the many complications occasioned by geological events, such as fluctuations in sea level, and the changes in the character of the human occupation of the region. Certain details of this correlation are controversial but it is apparent that, since late Glacial times there has been an improvement in climate. The progress of this improvement is interrupted by periods when the climate deteriorated. This evolution of climate has been expressed in several classifications by as many students.[97] Each of these is subject to criticism and none of them have been universally accepted. Recognizing this difficulty, we may only select, arbitrarily, one such classification as a background for the present study.

Blytt and Sernander[98] have classified late Glacial and Post Glacial climate in northwestern Europe. A brief résumé of this classification is listed below.[99]

Period	*Climate*
Recent	warmer and dry
Sub-Atlantic	cool and very wet
Sub-Boreal	dry, warm and continental
Atlantic	warmer, moist and oceanic
Boreal	warm, dry and continental
Sub-Arctic	sub-arctic to warm
Arctic	arctic

In North America there have been initiated researches which are similar in nature to those in northern Europe. These are, however, incomplete. Several hypotheses describing the evolution of climate have been proposed for southeastern Canada, the middle western United States and New England.[100] However, the relationship between conditions in these regions has not been discovered. As explained by Deevey,[101] types of climate and the evolution of climate in these regions are not expressed by developments in the same type of vegetation. Thus, for example, the profiles from Connecticut, Indiana and eastern Canada developed under different circumstances, if not at different times, because of their spatial relationship to the receding ice. Also the vegetation producing the profiles varied according to the latitude in which it was found and in relation to the ecological area in

[96] For an example of a method employed in developing chronology see Fromm 1938.
[97] For example. Blytt, 1882; Sernander, 1908; von Post, 1930; Gross, 1931.
[98] Blytt, 1882; Sernander, 1908.
[99] After a table from Zeuner, supplied by W. S. Benninghoff.
[100] Auer, 1903; Sears, 1932, 1937; Deevey, 1939; Eiseley, 1939; Smith, 1940.
[101] Deevey, 1939, pp. 719–721.

which each profile developed. It is obvious that the evolution of climate was not synchronous all over eastern North America and that it will be impossible to correlate developments in the separate areas until a sufficient number of profiles which show the overlapping of the several areas have been presented. The whole study will be materially aided by contributions from geology and archaeology. At the moment these data are so scarce and poor that they can hardly be said to exist.

Real progress in the development of a chronology in North America has been prevented by the lack of data. What data does exist, suggests that there is some similarity between American and European developments, however, the many gaps in the American data prevent any semblance of proof of synchronous developments in the two continents. It is possible, however, to use classifications, such as that presented by Blytt and Sernander for Europe, as a working guide to developments in America. In doing so, it must be recognized that the criteria by which the European periods have been defined have not been found in American profiles. The periods suggested in the present study are indeed most tentative.

This incomplete data from America appears to indicate that, following deglaciation, a tundra flora developed. This may be called Period 1. This flora appears only to have existed in scattered regions during late Glacial times and, since it developed slowly, only thin deposits accumulated before they gave way to a spruce-fir forest. The pronounced spruce maximum denotes a cool climate and, it is thought, this may be a reflection of a rather abrupt expansion of late Wisconsin ice sheets during Period 2. In fact it has been suggested that possibly this may be associated with the building of the Cochrane moraine, in Ontario. The end of the period saw the increase in fir forest and the development of a birch maximum. It is thought that this accompanied the cessation of the ice advancement and extended into times when the ice retreated and perhaps disappeared. The next period, Period 3, the first true Post Glacial one, brought a pine maximum. It was warmer than the preceding and it was also dry. This was followed by a still warmer but a moister climate which, on the coast, saw the development of an "oceanic" climate, if such may be said to exist. It is believed that the North American correlative of the Post Glacial Optimum, which has been identified in Europe, will eventually be found, if it has not already been identified, in this warm moist period.

Further changes saw a decrease in humidity so that a warm, dry or "xerothermic" period, Period 4, may be identifiable. During this time, according to Deevey,[102] the oak-hemlock forest of Connecticut changed to

[102] Deevey, 1939.

oak-hickory. There are some who suggest that this period may be equated with the Sub-Boreal in Europe.

The final period, Period 5, brings the developments down practically to modern times. The warm, dry, oak-hickory forests of Connecticut gave way to cooler and moisture oak-chestnut forests on the coast and to spruce-hemlock forests in the interior. In terms of European geochronology, the deterioration of the warm, dry period appears as the Sub-Boreal and the cooler, moister climate belong in the succeeding Sub-Atlantic.

Within these major periods of climate there are important minor variations and some hold that these, as well as the major ones, may be correlated with the European system. However, in view of the complexity of the problem and the scarcity of data, it seems better to avoid developing a too complicated hypothesis. Thus, while the succession of the major periods appears to be comparable, it is impossible to say whether these major periods were contemporaneous or not and likewise to determine whether the details of the changes are similar. Commenting on this situation, Smith has aptly said, "These minor variations, occurring almost rhythmically, show that while the European divisions of postglacial time outlined above apply in a general way to the eastern North American profiles, postglacial climate in eastern North America is perhaps better characterized as a series of climatic pulsations of more or less humid periods. The next to the last of the less humid periods of major importance is the 'xerothermic' period, described above. The profiles also indicate that the climate was warmer than now, during most of the time from the warming of late boreal time (the last of Period 2) nearly to the present."[103]

THE DATING OF THE FISHWEIR FROM THE HYPOTHETICAL EVOLUTION OF CLIMATE IN NEW ENGLAND

The mollusks, including the oysters, the diatoms, foraminifera, and barnacles, to say nothing of the trees and shrubs, represented by the stakes and wattles, are not foreign to the Boston Lowland at the present time. The marine borers and possibly some of the diatoms and foraminifera are not found in the region now. An analysis of the ecological requirements of the organisms shows that the climate, when the Lower Peat was formed, was probably slightly warmer than it is now and that, as the silt accumulated, the climate became cooler. The definition of this deterioration of the climate is, in so far as possible, completed by the analysis of the pollen from the deposits.

[103] Smith, 1940, p. 601.

The combined efforts of Benninghoff and Knox have produced a series of pollen profiles from which tentative interpretations of climatic evolution and chronology may be made. Benninghoff's data from the Lower Peat suggests that this layer first developed during a dry period and that its accumulation ended when conditions were becoming moist.

Knox, in a complicated discussion, has boldly combined the data from the peat with profiles from the silt and matched the resulting curves to the profile from the Wellington Marsh. On the basis of other studies he shows that the profile from the Wellington Marsh may be used, tentatively, as a master diagram to illustrate climatic evolution in this section of New England. According to his ideas, optimum climatic conditions may have preceded the deposition of peat, and the succeeding warm and dry climate may have begun to deteriorate soon after or during the formation of the Lower Peat. This deterioration continued, with some minor, but possibly significant fluctuations, during the period which saw the accumulation of the silt. At the end of this period, cool and moist conditions had evolved and these, hypothetically, gave way to the possibly slightly warmer and dryer conditions of the present day.

The evidence for this account of climatic evolution is indeed tenuous. Even including unpublished data, there is little information which will guarantee that the profile from the Wellington Marsh is complete. The profile from the building excavation is not above suspicion. It is drawn from a single series of samples, which in the case of the section from the silt are located some distance apart. Evidence of additional and significant fluctuations of climate may have been present in layers which are not represented in the profile. A further difficulty may be found in superimposition of the silt profile upon that of the peat. In a discussion of the succession of these deposits (p. 162), it was carefully pointed out that possibly the deposition of silt did not follow immediately after the peat ceased to develop. Thus the two profiles may not be continuous, being separated by a gap the size of which is in proportion to the length of the intervening time interval. Knox has attempted to establish the validity of his profiles and this, by implication, would prove the continuity of the deposits. With due regard to his efforts, his statements that the argument is tentative must be emphasized, —without question the data is not sufficient to prove the case.

With these qualifications, the arguments of Benninghoff and Knox may be tentatively accepted. In a general way, the hypothetical evolution of climate, interpreted from the pollen profiles, falls within the limits of Periods 4 and 5 (p. 189). Knox's interpretation places the deposits surrounding the Fishweir in Period 4 and Benninghoff's ideas suggest that these deposits were originated a little later, in Period 5.

The actual dating of the structure is a further ramification of the problem. There is no data in North America which permits the dating of deposits. This can only be done at present by correlating the evolution of climate with the dated sequences which have been discovered in Europe. The tentative and a priori basis of such a correlation has been pointed out.

The relation of the periods, suggested by Blytt and Sernander for Europe, to theoretical developments in America has been suggested, and some measure of the disagreement among contemporary students concerning the validity of this relation has been noted (p. 188). In view of this, it is only possible to accept with reservations, Knox's hypothesis that the Fishweir was used between 1700 B.C. and 1400 B.C., during the sub-Boreal period. Benninghoff, for reasons as valid as those of Knox, has suggested that the Lower Peat may be assigned to the late sub-Boreal or early sub-Atlantic period. Placing the Lower Peat in this period does not supply a date for the structure because the stakes were driven after the accumulation of the peat had been arrested. A date based on Benninghoff's estimate is about 1000 years later than the date provided by Knox. In view of the conditions under which these estimates were made, the discrepancy between them is not surprising. The Fishweir cannot be dated more accurately until more is known of climatic evolution in New England and until a geochronological time scale, applicable to the northern hemisphere has been established.

A GENERAL SUMMARY

THE preceding pages have been concerned with numerous problems which arose during the attempt to interpret the significance of the discovery of the Fishweir. In themselves these problems required the attention of specialists who have made significant contributions in their specific fields. Studies of the numerous organisms have produced identifications and ecological or other interpretations which provide specific information concerning the Charles River estuary. This data will be of value in each particular field. These studies also indicate the lacunae which exist in the knowledge of the area and so may be used to give direction to future work. The analysis of the wood from the stakes and wattles has produced information concerning changes in its characteristics which have taken place during its history. Implied in this study are additional problems which concern the effect of various environments and of age upon prehistoric wood. The ecological data and the analysis of the pollen has added to the existing information concerning the evolution of climate in New England. In each case the investigations have produced certain facts which cannot be ignored and also hypotheses which must be taken into account in any study of the region.

The excavation of the stakes and wattles produced information concerning the location of the Fishweir and also data dealing with certain deposits. This indicated that humans were living in the Charles River estuary at a time when the level of the sea, in relation to that of the land, was about fifteeen feet eight inches lower than it is at the present time. The establishment of this fact proposes a geological problem of some magnitude. The actual submergence of the land might possibly be explained by strictly geologic phenomena. However, in order that the interpretation of the significance of this submergence may be adequately explained the geologist must synthesize the data coming from other fields, many of which are represented in the preceding analysis.

The present data indicates that submergence was the last change in the relative level of land and sea. No evidence of emergence was uncovered and there is no evidence which proves that conditions are now static. It is probable that the submergence lasted into geologically recent times, if it did not continue to the present day. The problem of supplying a chronology for this movement has been discussed at length and tentative dates have been offered. If these have any merit, it appears that the first record of the

submergence of the land noted in the building excavation may be about 3000 B.C. It is probable that the movement in eastern Massachusetts had begun previous to the time recorded in the Charles River estuary. The conclusion is inescapable that the Fishweir was used during a period of rising sea level which began before the structure was built and which may have lasted to the present day.

A submergence of this magnitude cannot be explained by hypothetical modification of the locality and so it is probable that this submergence is, in one way or another, the result of adjustments of level which have followed the recession of the glacial ice from New England. A discussion of the possible explanation of these adjustments has been included, but the lack of data permits only the presentation of an hypothesis. It is to be hoped that future researches will contribute to the clarification of this problem of submergence and that eventually it may be possible to correlate the changes in level with some established chronological scheme.

APPENDIX
AND
BIBLIOGRAPHY

APPENDIX

NOTES ON SOME MODERN FISHWEIRS

FREDERICK JOHNSON

ONE of the first questions asked about the structure which has been called the Boylston Street Fishweir was, what is it and why were all the stakes driven? It seemed only fair to investigate earlier assumptions that the structure was a fishweir. A rapid survey of the literature and a hasty trip along the coast of Maine between Cundy's Harbor and Bucksport was made to satisfy this curiosity. Some of the information thus gathered was not strictly applicable to the present study but, since descriptions of fishweirs seemed to be few and far between, this data has been recorded here.

On the coast of Maine, "weiring" is a specialized industry carried on by a conservative group of very resourceful people. The most successful weirs, and for that matter many of the less successful ones, have been maintained by a single family for several generations. The family owns the area covered by the weir either legally or by a type of common consent which is far more binding than any written law.

The weirs are run "on shares"; that is, the owner of the weir pays the cost of building and maintaining it and he pays the men who work for him by the hour while they are collecting the material or building or repairing the structure. When these same men are "fishing" the wier, i.e. gathering the fish caught, they only receive a percentage of the receipts from the sale of the catch. After the weir is built in the spring the men must wait for the fish to come in and so, in good Maine fashion, the "weirmen" go lobstering.

Weirmen are thoroughly familiar with the habits of the fish they catch. They spend a great deal of time watching the fish and they can talk for hours about the behavior of schools, mentioning even, the actions of certain strange individuals. They are equally familiar with the locality. They know the tides, the effect of the winds, bright days and rainy days. Even seemingly insignificant changes in the bottom are well known to them.

The plans of weirs have been developed on the basis of this experience. These plans are the only indestructible things about weirs, for the stakes and brush of which they are built are usually carried away by the ice and by winter storms. Besides the location of the weir these plans are inherited from preceding generations. The plans, which are not always drawn, change

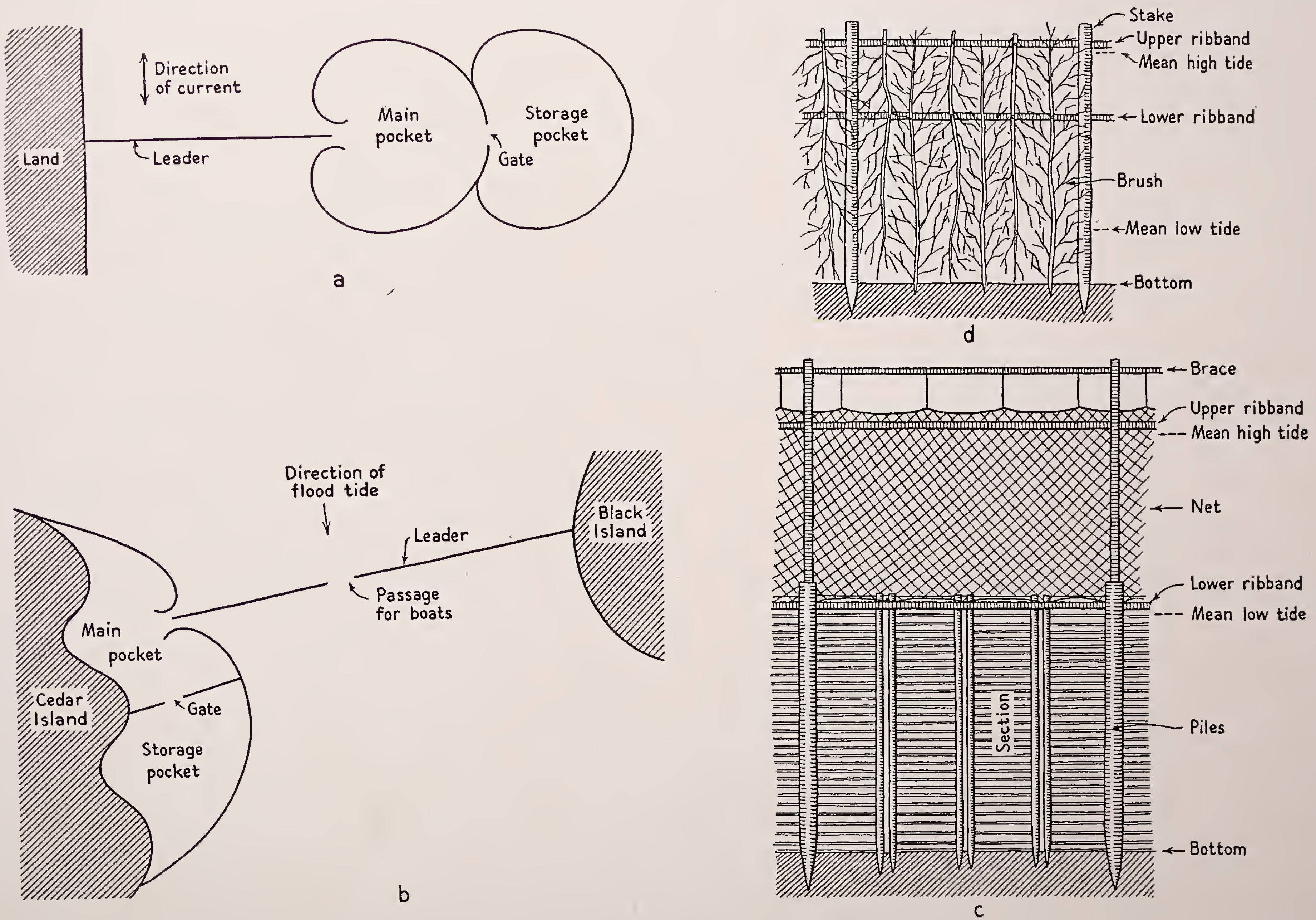


FIG. 15. Diagrams of herring weirs. a. Plan of simple brush weir. b. Plan of weir owned by Sherman Jameson, Friendship, Maine. c. Construction of brush weir. d. Construction of Jameson's weir.

as they pass from father to son. From time to time changes in conditions in the locality or in the habits of the fish have been observed and the weirs are modified accordingly. In making such changes, the weirmen exhibit how clever and resourceful they really are. In spite of this, weirmen are strangely conservative. Upon my expression of surprise when one very successful weirman told me he had never been "aboard" another weir, he said that he did not need to. He said that weirs must be made to conform to local situations and that he could learn nothing from somebody else's weir. He ended his discussion by saying, "all weirs are alike but no two are the same." While this gentleman was not interested in weirs which were designed for herring and mackeral, as was his, he was very much interested in a second type, an alewife which we visited.

Weirs are special arrangements of various types of fences. There are several types of construction used in building weirs but these types are principally variations in details. Essentially, heavy stakes are driven vertically into the bottom and horizontal "ribbands" are fastened to these. Yellow birch brush is then nailed to the ribbands, the butt ends of the brush being nailed first to the upper ribband and then to the lower ribband (Fig. 15, *d*). These are alternated in order that the branches may cover all the space most efficiently. It was explained that no great barrier was needed to prevent herring or mackeral from passing because they will only travel in a school. In some places netting is used instead of brush but, since netting is expensive, it is usually employed only where necessary.

Weirs designed to catch both herring and mackeral have one fundamental plan (Fig. 15, *a*; Pl. XIII, *a*). A "leader" runs out from the shore at right angles to the current. The seaward end of the leader is located in a place where there is never less than six feet of water at low tide. The end of the leader stands at the entrance to a heart-shaped "pocket" (Pl. XIII, *b*). Frequently additional "storage pockets" are added to the main pocket.[1] This arrangement catches schools of fish which move with the current. When the school runs into the leader it turns toward the deep water and works its way into the pocket. Once in the pocket, the school swims around following the wall. It does not go out the entrance, for the curving ends of the walls are carefully designed so that they will turn the school toward the center of the pocket. The storage pocket is used when it is impossible to dispose of a catch quickly. This pocket is closed off from the main pocket by

[1] I am told that in the Bay of Fundy, where there is an extraordinary range in tide, the pockets go dry at low tide. In these weirs a storage pocket would be useless because the fish would die when the tide went out, leaving them on mud flats. The fish have to be collected from the weirs on every tide. This is frequently done in ox carts.

a gate. The weirs are fished by means of small purse seines. The seine is set from dories or even motor boats around the wall of the pocket so that when it is pursed it catches all the fish in the pocket.

There are many variations of the storage pocket. These depend upon the local situation and the ingenuity of the weirmen. One of the most complicated arrangements of pockets was seen in a weir near the center of the town of Searsport. In this weir several pockets and various arrangements for fishing the weir had been incorporated in the plan. Plate XIII, *c*, illustrates a very simple brush weir, near Searsport, to which has been added a frame supporting a seine. This is an ingenious combination of storage pocket and fishing device. The seine can be lowered to form a pocket to catch a school of fish coming from the main pocket. When the time comes to fish the weir the seine can be handled from the frame. When the seine is not in use it is pulled up above the water level to dry.

Brush weirs are used, for the most part, in places which are protected from storms and heavy seas. The brush walls of such weirs catch the wind and wave action will break them down. Plate XIII, *a*, illustrates how a weir may be damaged by wind. A section of the leader has been blown over. In this case the weir had been in use about two months and this was not the first time it had been damaged. The stakes supporting the leader had not been broken but they had been blown over so that the section which was driven into the bottom had been uprooted. Under these circumstances no remains of the stakes would have been left in the mud. Such weirs will not last through the winter. Whatever the winter storms leave the ice will ruin. Most of the stakes are uprooted but a few of them may be broken off between the mud-line and Mean High Water.

One interesting weir, which varies from the general plan, is owned by Mr. Sherman Jameson of Friendship, Maine. This weir is located off Cedar Island, one of the outermost islands off Friendship in Muscongus Bay. The main and storage pockets are designed to include two small coves of Cedar Island (Fig. 15, *b*) in which there is thirteen feet of water at low tide. The leader runs across the channel between Cedar and Black Island (Pl. XIII, *b*). There is a gap some eight feet wide in the leader which permits small boats to use the channel. Curiously enough this gap does not effect the efficiency of the leader. Mr. Jameson said that no school of fish had ever gone through it. For several reasons connected with the location of this weir far out in the Bay, it catches fish both on the flood and ebb tides. Usually weirs work best when the tide is flooding and only rarely do they catch fish on the ebb.

Mr. Jameson's weir is located in an extremely exposed position in regard to both wind and sea. Throughout the long history of this weir attempts

have been made to strengthen it. The present stage of the development of the construction is extremely interesting. The construction for the walls of the pockets is similar to the construction of the leader. Piles eight inches in diameter were sharpened and driven into the bottom. These piles were cut off just above Mean Low Water (Fig. 15, *c*). The lower ribband was spiked to these piles. A pole or net support four inches in diameter and about fourteen feet long was spiked to the top of the pile. This net support was set at an angle of about seventy degrees pointing into the pocket. The upper ribband was spiked to this net support above the level of Mean High Water and a brace running parallel to the ribband, was fastened to the top of the net support. A net was set between the lower ribband and the upper ribband. The lower edge of the net was lashed to the lower ribband. The upper edge was fastened with long lashings to the brace. The angle of the net support was such that it prevented the net from chafing on the net support or on the upper ribband. The net, while it would catch the wind to some extent, did not do so as much as brush would do. Then too, during stormy weather, the lower edge could be unlashed and the net furled on the upper ribband. When no fish are running the net is cast loose and hung over the brace and support to dry.

The part of the weir which is below water is closed with "sections." These were made with two spruce poles about fifteen feet long. To these were nailed wooden plasterer's laths. The laths were set one-half inch apart in sections used in the pockets and six inches apart in sections used in the leader. In the latter case the larger opening allows the current to pass through but not the fish in schools. About one foot of the lower ends of the section poles was left free of laths. A section was then driven into the bottom until the first lath rested upon it. The upper ends of the section were nailed to the lower ribband.

This description of the main construction of the weir does not include many additions to take care of specialized circumstances. To combat surf, which breaks the sections down, crib-work in the form of a small breakwater has been added at various places. There is also a system of stays and guy wires which support the structure against the wind.

In the fall when the fishing is over the net is removed and the sections are pulled out. The piles are left to survive as best they may. Drifting ice flows knock many over, and ice, which freezes to the tops of the piles, may lift them out as the tide rises. However, since the piles are below water, many of them survive the winter. Those that do resist the elements last about three years after which time they are usually weakened by borers which work at the mud line. Frequently old piles may break off at the mud

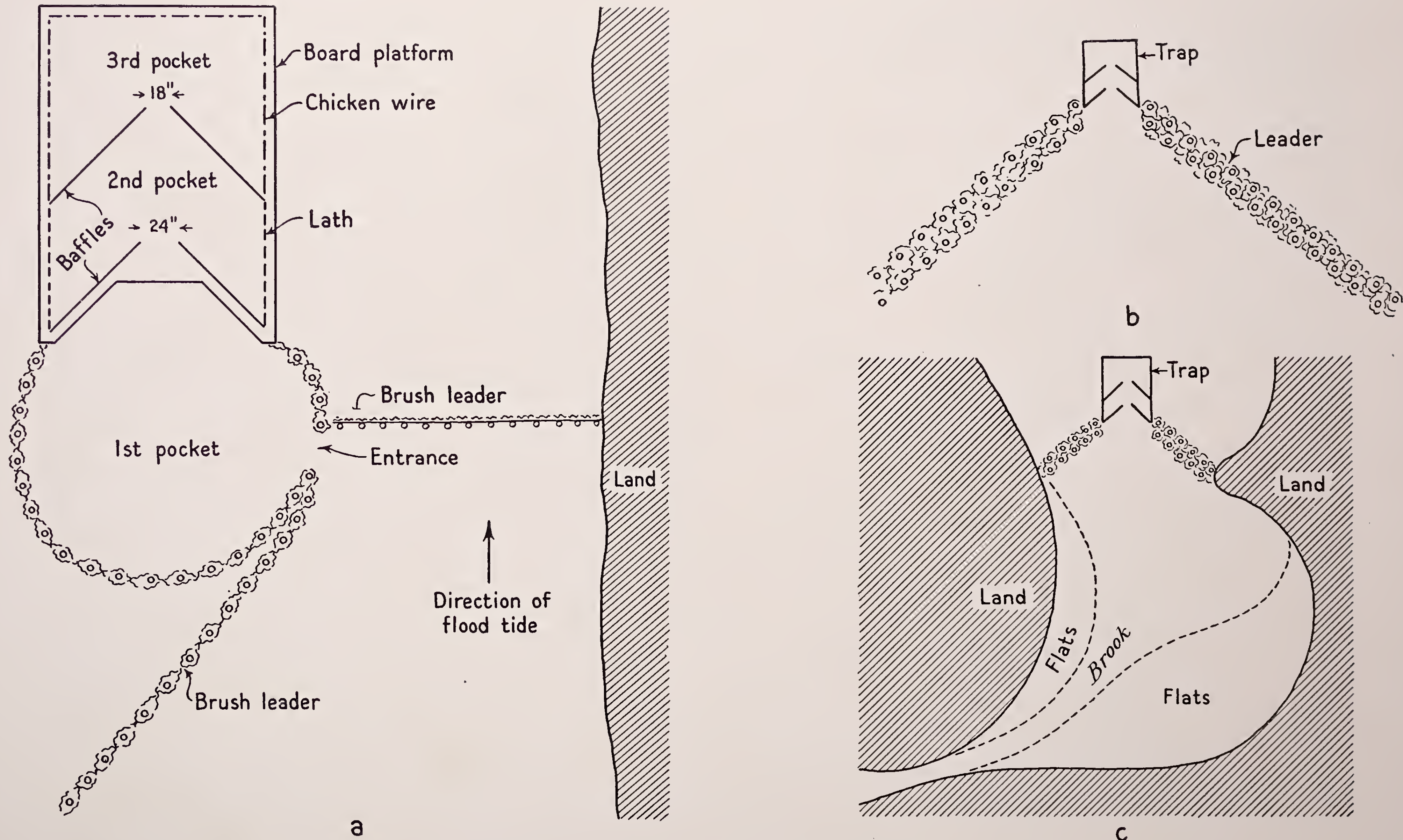


FIG. 16. Diagrams of alewife and smelt weirs. a. Plan of alewife weir in the Thomaston River, Maine. b. Plan of smelt weir in Searsport, Maine. c. Plan of smelt weir in Stockton Springs, Maine.

line. Mr. Jameson and all the other weirmen said that they attempted to keep the bottom clear of old stakes or piles. Whenever possible these were pulled out because these old stakes interfered with new construction.

Weirs to catch alewives work on a principle which is similar to that employed in herring weirs. An area is fenced off and entrances arranged by means of baffles (Fig. 16, *a*). There are, however, some important differences in plan and these are due to the habits of alewives. These fish do not run in schools in exactly the same way that herring or mackeral do. During the spawning season the fish run up the river with the flood tide. They run at a more or less constant rate, in large or small numbers, according to the stage of the season. The alewives which are good to eat are those which run up the river. Those which have spawned and are running down the river to the sea are called "racers." Racers are very thin and, being a bony fish, there is little or nothing fit to eat on them. A weir to catch alewives must be built in the estuary of a river where there is a range of tide amounting to several feet,—six to ten, if possible. At the present time there are laws controlling the number of alewife weirs which may be constructed on a river and these laws also specify the length of the leader and the size of the structure in general. It is not permissible to block the channel of a river completely with a weir or its leaders.

A typical alewife weir is maintained by Mr. Charles D. Young in the Thomaston River, Thomaston, Maine (Pl. XIV, *a*). This weir is built every spring as soon as the ice goes out of the river. It is sometimes destroyed by freshets carrying logs and other flotsam, including ice which had been stranded upon the banks.

An alewife weir has to be built more carefully than a herring weir. Alewives are not easily stopped by a barrier of brush for they will wiggle their way through any aperture that they can find. Such weirs can be built with brush but they are not efficient and they are more liable to be damaged by the strong currents in a river. For these reasons chicken wire and plasterer's laths are used throughout, except for the wall of the first pocket and the leaders (Fig. 16, *a*).

In order that the fish may be gathered easily, a flat board platform is built under the second and third pockets (Fig. 16, *a*). This platform is fastened to small piles driven into the bottom and sawed off at low water level. The platform goes dry at low tide.

Long poles are driven into the bottom around the outside edge of the platform and chicken wire is attached to these. The chicken wire surrounds the third pocket. The outside wall of the second pocket is closed in with laths. One of the reasons for this is that, when the baffles are in place the

first and second pockets are dark. The alewives head for the light in the third pocket (Fig. 16, *a*). A board reinforces the chicken wire where it meets the platform and another board runs around the upper edge of the wire, just above the level of high tide.

On the down-river end of the platform long poles are driven, eighteen inches apart, in an arc which is about three-quarters of a circle. Brush from gray birch is woven tightly among these poles leaving only an entrance about two feet wide on one side (Pl. XIV, *b*). This is the wall of the first pocket (Fig. 16, *a*).

The second and third pockets are made by dividing up the area of the platform with lath baffles. The baffles are made in sections which are nailed to long poles driven through holes in the platform into the bottom. The entrance to the second pocket is about twenty-four inches wide and the entrance to the third pocket is about eighteen inches wide (Pl. XIV, *c*).

The structure is completed by the addition of two leaders (Fig. 16, *a*; Pl. XIV, *a*). One leader runs from the upstream side of the entrance across the current to the shore. The second leader runs from the other side of the entrance down the river. It is set at a slight angle with the current so that its end, about one hundred feet away, is in line with the outside edge of the weir. This provides the maximum coverage of the river permissible by law.

Fish are caught in this weir as they come upstream with the flooding tide. They follow the leaders into the first pocket which is relatively dark. They follow the light through the entrances until they arrive in the third pocket. When the tide goes down they are left there high and dry to be removed with a dip net.

The law requires that such a weir shall be removed by a certain date in the early summer. Mr. Young explained that, even were this not so, it was advisable to remove the weir when the season was over. Any remaining bit of construction, particularly the piles in the bottom, would make reconstruction the next spring very difficult.

The third type of weir, made to catch smelts, is found on mud flats below the mouths of brooks. Such weirs are high and dry for an hour or so before and after low tide.

The weirs are built in the shape of a chevron with the apex pointing out to sea. The sides of the chevron are the leaders. These are made by driving stakes vertically into the mud and weaving, horizontally, a thick mass of brush among them. The top of the leader lies below the level of Mean High Water and it may be only three feet high above the mud flat.

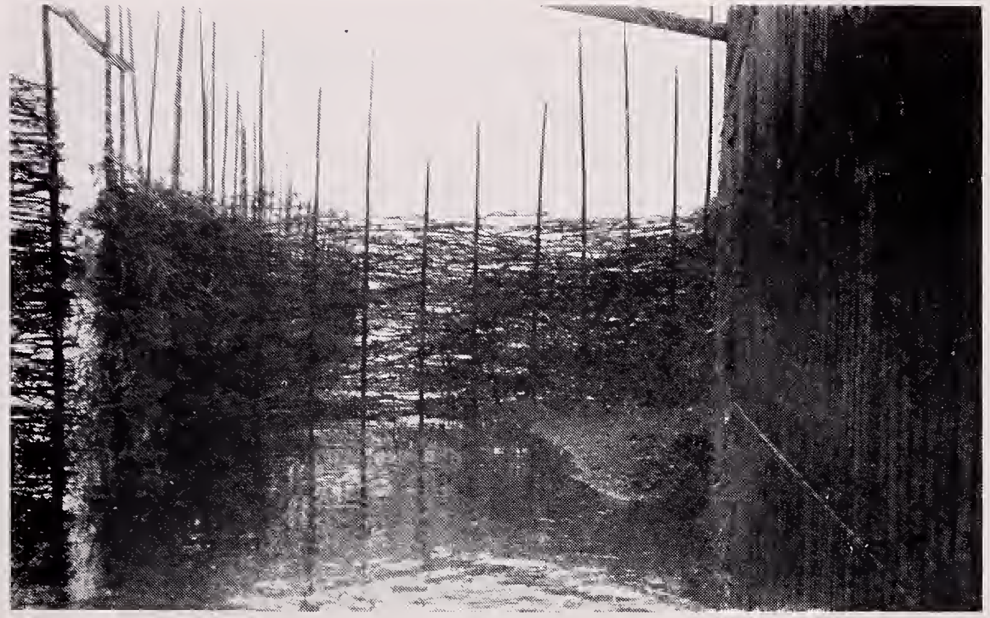
The trap is located at the apex of the chevron. It is in the form of a box,

Plate XIII

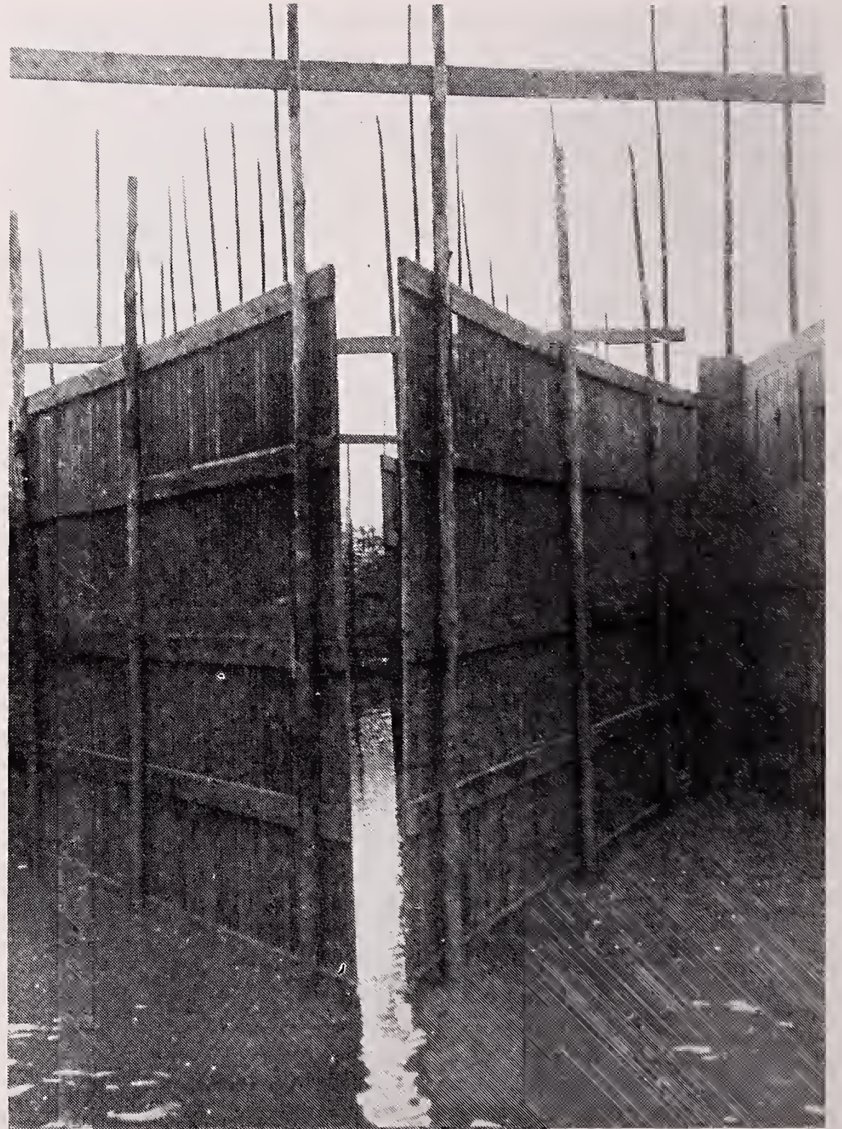
Modern fishweirs on the Maine Coast.

a. Fishweir located near Lincolnville Beach, Maine.
b. Jameson's Weir, Friendship, Maine. Looking out through entrance and showing position of leader.
c. Weir at Searsport, Maine, showing device for handling seine.

a



b



c

Plate XIV

An alewife weir in the Thomaston River, Maine.

a. View of weir looking down river at high tide.
b. View of first pocket from inside weir to show construction of wall.
c. View of weir looking down river through entrances to show baffles at low tide.

made of plasterer's laths set about one-quarter inch apart. The trap is the same height as the leader. There are two sets of baffles in the box (Fig. 16, *b*, *c*). One of these is a continuation of the leaders. The second set divides the box into two pockets. The smelts are scooped out of a second pocket with a dip net at low tide.

Smelt weirs of this type may be set opposite a brook on a wide expanse of mud flat, as in the "Cat Hole," Long Cove, Searsport (Fig. 16, *b*), or they may block off a brook, as does the one in Stockton Springs (Fig. 16, *c*). As the tide floods and covers the weir the smelts run over it and go on up the river. When the tide turns smelts which have not reached the fresh water, return toward the sea, to be guided into the trap by the leaders.

A fourth type of weir is not found, to my knowledge, on the Maine coast. This type was used in the Pamunkey River, Virginia until about one hundred years ago. ". . . At the entrance of the smaller creeks, or guts, branching off from the main streams was built a barrrier of poles several feet apart driven upright into the ever present mud at low tide when the water is out of the place. . . . The 'hedges' were made low enough in some instances so that the fish could pass over their tops at high tide. Then, as the water went out on the ebb, they would be barred from returning to the river. In the enclosures where the water might be from six to eight feet deep the hunters could shoot the impounded fish with arrows or spear them with iron-pointed prongs. In the deep holes the sturgeon caught by the 'hedges' were hooked with a jig-hook. They would sometimes jump the barrier. 'Hedging' was more practicable near the headwaters of the rivers, frequently above tide water (salt water may be meant here) . . . The lattice-work of the 'hedges' was so constructed as to slope upstream. I might add that similar weirs may be seen in the streams of the Cherokee country. In that region stones are available for construction and are used in the wings of the dam, the trap of slats being set at an opening where the fish are obliged to pass."[2]

It is strange that there are no historic references which locate Indian fishweirs in eastern Massachusetts. We do know that the Indians built them but we are not sure just how they did it. In various streams and in some shallow rivers there are lines of stones which are believed to be the remains of Indian fishweirs. One well known arrangement of stones used to be visible at The Weirs, New Hampshire, near the outlet of Lake Winnepesaukee. However, if these lines of stones are the remains of weirs they are not comparable to the Boylston Street Fishweir.

The Boylston Street Fishweir was buried beneath some thirteen feet of

[2] Speck, 1928, pp. 359–360.

silt when the colonists arrived on the Charles River so they did not see it. They did note the abundance of fish in the Charles and Mystic Rivers and, according to William Wood, they built a weir in Watertown. It is hard to believe that an Indian weir had not preceded the one which he describes. Wood writes, "Halfe a mile westward on this plantation (New-Towne), is Watertowne; a place nothing inferior for land, wood, medoe, and water to New-towne. Within half a mile of this Town is a great pond, which is divided between those two Townes, which divides their bounds Northward. A mile and a halfe from this Towne, is a fall of fresh waters which conveigh themselves into the Ocean through Charles River. A little below this fall of waters, the inhabitants of Water-towne have built a Wayre to catch Fish, wherein they take great store of Shads and Alewives. In two Tydes they have gotten one hundred thousand of those fishes: This is no smalle benefit to the plantation."[3]

In deciding whether the Boylston Street Fishweir is properly named it remains to determine the characteristics which define a fishweir. Upon reflection, it will be seen that a weir can only be identified through the stakes which might survive the rigors of the climate and remain in the bottom. Further, it is apparent that the stakes will be found in some sort of order, from which a plan of the weir may be reconstructed. There are plans which include leaders and various types of pockets and also plans of weirs which are simply barriers set between the banks of streams. The plan of the Boylston Street Fishweir (Fig. 4) shows no arrangement of stakes which might have been a pocket. If the lines of stakes were part of a barrier there must have been some peculiar arrangement of the ends of the lines, for available contours show no banks anywhere near the building excavation.

The hypothesis that the structure is a weir is not untenable if it is also assumed that an arrangement of stakes to form a pocket, which would actually prove the assumption, lies outside the building excavation. The idea that the structure is a fishweir is given some weight by the lack of any other satisfactory explanation. Nelson's suggestion[4] that the structure was a spat collector is important and should not be ignored. It does seem however that the fishweir idea is a little more acceptable. There is a rather definite plan to the structure which would hardly seem necessary if it were to be used to collect oysters. Also the stakes were sharpened and driven with some care which indicates an amount of unnecessary work to put into an oyster spat collector. The discovery, by Bailey and Barghoorn,[5] that, under present climatic conditions, the stakes were cut between the middle of April and the middle of June lends some weight to the hypothesis that the structure was a

[3] Wood, 1634, p. 41. [4] Pp. 61–62. [5] P. 84.

fishweir. This is the opportune time of year to build or repair a weir for alewives and other fish that run up the rivers during the spring and early summer. It is only fair to add also that this would be a good time to prepare a spat collector for the oyster season. In view of these remarks no explanation of the structure can be offered but the hypothesis that the structure is a fishweir appears to be as good as any other which has been offered.

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